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Sustainable Urban Residential Forms in an Oil-constrained Future: implications for planning in an Australian city context.

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Sustainable Urban Residential Forms in an Oil-constrained Future:

Implications for planning in an Australian city context

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A thesis submitted in total fulfilment of

the requirements of

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Abstract

The twentieth century has been the era of abundant supplies of petroleum (oil) that has been a significant catalyst for expansion of cities into sprawling suburbs. The thesis investigates the likely effects of future oil supply constraints on the planning of sustainable urban residential forms in the context of an Australian coastal city. The problem is addressed by research questions in three parts. Firstly what are the dependency relationships of urban residential development on the oil-based economy and the implications for growth management of major Australian cities? Secondly, how might the land development and building construction factors; and the land use planning framework factors influence urban residential forms in the Australian city context? Thirdly, how might land use planning assist the transformation of urban residential forms towards an oil-constrained future? The three research questions have been investigated through a pragmatic mixed methods approach involving literature and documentary analysis, case studies, grounded theory and a scenario planning method, as applied to the reference City of Gold Coast in South East Queensland. A refined integrated conceptual framework and suburban transition model developed from the research are applied to scenarios of adaptive and maladaptive oil adaptation strategies, which suggest how land use planning may guide transformation of urban residential forms towards an oil-constrained sustainable city. The findings point to four refined grounded theories that are offered as original contributions of the thesis to sustainable development planning theory and practice relevant to sustainable urban residential forms in an oil-constrained future. The four theories are: that oil constraints will gradually affect all types of urban residential buildings at the site scale; that adaptive design is needed for sustainable urban residential forms at the precinct scale; that oil depletion will increasingly affect urban communities at middle–outer city scales; and that transformative planning policies are needed for the urban form at the whole range of scales. Strategic planning for oil depletion is suggested in three phases: a mitigation phase of conserving oil supply and reducing demand; a ‘transitional city of tomorrow’; and ultimately towards an ‘oil-constrained city of the future’. The thesis contributions extend current theory and practice in planning, urban design, sustainable development and urban metabolism by linking all these disciplines into the grounded theories, integrated conceptual framework and models for an oil-constrained sustainable urban form that has application to Australian and other western cities.

Declaration by candidate

This thesis is submitted to Bond University in fulfilment of the requirements of the degree of Doctor of Philosophy. This thesis represents my own original work towards this research degree and contains no material which has been previously submitted for a degree or diploma at this University or any other institution, except where due acknowledgement is made.

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Peer reviewed publications relevant to the thesis:

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Brewster, RJ 2014, ‘Pathways to an oil-constrained city’ in N. Marchettini, CA Brebbia, R. Pulselli and S. Bastianoni (eds.), *The Sustainable City IX: Urban Regeneration and Sustainability*, WIT Press, Southampton, pp. 351-363.

Brewster, RJ 2016, ‘Relative vulnerabilities of urban residential development to oil depletion: pilot case studies of a representative building typology in the Australian context’, in CA Brebbia and A Galiano-Garrigos (eds.), *The Sustainable City XI*, WIT Press, Southampton, in publication.

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The Canadian Institute of Planners conference in 2005 was a turning point in my professional career. Leon Krier, a grandfather of new urbanism, exhorted the audience to read a recently published book by American social commentator James Howard Kunstler (2005) – *The Long Emergency-surviving the converging catastrophes of the twenty-first century*. This exposition of future scenarios underpinned by looming 'peak oil' was an epiphany moment that started a research journey about a 'global wicked problem', which has become the context of this planning thesis. I had been involved in land use planning for nearly four decades, mainly as an urban planning consultant based at the Gold Coast, Australia, but also involved in environmental planning at Commonwealth and Queensland State Government levels. Never had I been exposed to the possibility of a peaking in global oil production, and certainly not in my first career as an Air Force pilot having a bird's eye view of the world. More recently I have been employed in the Queensland Government planning department, developing strategic responses to climate change, which is highly relevant to the issues of this research on the planning implications of peak oil.

I have become indebted to many pioneers in the investigation of peak oil and its implications including Colin Campbell and Professor Kjell Aleklett, leaders in the Association for the Study of Peak Oil and Gas (ASPO); my colleagues at ASPO Brisbane; Richard Heinberg of the Post Carbon Institute; and the many enlightened colleagues in the planning profession including Peter Newman of Curtin University and John Byrne of Queensland University of Technology. My fellow travellers in the peak oil journey have been a source of inspiration and support.

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Abbreviations and acronyms used in this thesis

ABS	Australian Bureau of Statistics
ALCAS	Australian Life Cycle Assessment Society
ALP	Australian Labor Party (at federal and state levels of government)
AS	Australian Standard
ASPO	Association for the Study of Peak Oil and Gas (founder Dr Colin Campbell)
BASIX	New South Wales Landcom building sustainability assessment tool 2003
BREEAM	Building Research Establishment Environmental Assessment Method
CBD	Central Business District(s) of a city
CHP	Combined heat and power
CNG	Compressed natural gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CTL	Coal-to-liquids
E10	Motor petrol (gasoline) blend containing up to 10 per cent ethanol
EIA	Energy Information Administration (USA)
EROEI	Energy return on energy invested – a ratio of energy return on the energy used to produce an energy source
EV	Electric vehicle
GBCA	Green Building Council of Australia
GCCC	Gold Coast City Council
GDP	Gross domestic product
GHG	Greenhouse gas
GTL	Gas-to-liquids
HEV	Hybrid electric vehicle
IEA	International Energy Agency
IPA	Integrated Planning Act
IPCC	Intergovernmental Panel on Climate Change
IRTP	Integrated Regional Transport Plan for South East Queensland
ISO	International Organization for Standardization. See http://www.iso.org
LCA	Life cycle analysis
LEED ND	Leadership in Energy and Environmental Design for neighbourhood development
LNG	Liquefied natural gas
LNP	Liberal National Party (at Queensland level of government)
LPG	Liquefied petroleum gas
LTO	Light tight oil (also called shale oil)
MFA	Material flow analysis
NGL	Natural gas liquids (liquids extracted from gas in plants)
Non-OECD	non-Organization for Economic Cooperative Development nations, including China and India

OECD	Organization for Economic Cooperation and Development
OPEC	Organisation of the Petroleum Exporting Countries
OSM	Off-site manufacture
P-AMOD	Public-active mobility oriented development (See section 6.3.2 (f))
PIA	Planning Institute of Australia
PrecinX^{TM}	New South Wales Landcom precinct wide sustainability assessment tool 2009
PV	Solar photovoltaic
PVC	Poly Vinyl Chloride (type of widely used plastic)
QPP	Queensland Planning Provisions
SEQ	South East Queensland (Australia)
SEQRP	SEQ Regional Plan
SPA	*Sustainable Planning Act* 2009
TOD	Transport oriented development
UK	United Kingdom
USA	United States of America
USGS	United States Geological Survey
VAMPIRE	Vulnerability assessment for mortgage, petrol and inflation risks and expenditure – model developed by Hence Dodson and Sipe (2008a, 2008b) See section 3.1.1
VOC	Volatile organic compound
WEO	World Energy Outlook (published by the IEA)
WTI	West Texas Intermediate (US standard grade of crude oil for oil price reporting)

Conversion factors

bbl	Barrel (of crude oil) - a barrel is the equivalent of 42 U.S. gallons or 159 litres
CO_{2e}	Carbon dioxide gas (tCO_2e -Tonnes of carbon dioxide equivalent)

<u>Energy conversion factors</u>

J	Joule (metric unit of energy) The joule is the standard unit of energy in general scientific applications. One joule is the equivalent of one watt of power radiated or dissipated for one second. [ABARES 2011]
kJ	kilo Joule = 10^3 joules (1000 joules)
MJ	Mega Joule = 10^6 joules (1 million joules)
GJ	Giga Joule = 10^9 joules (1 billion joules)
PJ	1 Petajoule = 10^{15} joules, or 278 gigawatt hours, is the heat energy content of about 43,000 tonnes of black coal or 29 million litres of petrol. [ABARES 2011]
kWh	1 kWh (kilo Watt hour) = 3600 kJ = 3.6 MJ
MWh	1 MWh (megawatt-hour) = 3.6 GJ
Mtoe	million tonnes of oil equivalent 1 Mtoe = 41.868 PJ

1m^3 of natural gas	= 39MJ	= 10.8kWh
1 litre of gasoline	= 34MJ	= 9.4kWh
1 litre of diesel fuel	= 40MJ	= 11.1kWh

Glossary

Activity centres — Centres within urban areas that provide shops, employment and services and attract activity from the surrounding areas. Activity centres include central business districts, major shopping centres, smaller neighbourhood centres as well as specialist centres like hospitals and universities.

Biofuels — Alternative fuels made from plants such as corn, canola and sugar cane, waste or food co-production feedstocks. These include ethanol and bio-diesel used as fuels and fuel additives.

Building materials — Materials and products used in the construction or assembly of building components [AGO 2006: 9]

Business as usual — For the purpose of this study, an approach to undertaking urban built environment development activities and processes, which assumes no significant changes in the moderating control variables, or external environmental circumstances over time.

Climate Change — 'On the balance of probabilities and not as a matter of belief, the majority opinion of the Australian and international scientific communities [is] that human activities resulted in substantial global warming from the mid-20th century, and that continued growth in greenhouse gas concentrations caused by human-induced emissions would generate high risks of dangerous climate change'. [Garnaut 2008: 15]

Climate change adaptation — The process of adjustment to climate changes that will occur despite efforts to reduce greenhouse gas emissions. Adaptation planning actions can adjust natural or human systems in response to climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. These actions will contribute to increasing resilience of human settlements to climate change.

Climate change mitigation — Involves actions that reduce the impact of human activity on the sources of greenhouse gases or enhance their sinks, aimed at reducing the extent of global warming.

Coal seam gas — Methane held within coal deposits, bonded to coal under the pressure of water. It may also contain small amounts of carbon dioxide and nitrogen (also referred to as coal seam methane and coal bed methane). [ABARES 2011]

Crude oil — Naturally occurring mixture of liquid hydrocarbons under normal temperature and pressure. [ABARES 2011]

Ecologically Sustainable Development (ESD) — Development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends. [*Australian National Strategy for Ecologically Sustainable Development 1992*]

Eco-cities — A term devised by Richard Register to include the principles: build the city like the living system it is; make the city's function fit with the patterns of evolution; follow the builder's sequence – start with the foundation with a land use pattern that supports the healthy anatomy of the whole city; reverse the transportation hierarchy to plan for pedestrians first, and lastly cars; build soils and enhance biodiversity. [Register 2006: 183-184].

Eco-neighbourhood or district — A neighbourhood or district with a broad commitment to accelerate neighbourhood-scale sustainability. Eco-districts commit to achieving ambitious sustainability performance goals, guiding district investments and community action, and tracking the results over time. [Portland Sustainability Institute]

Eco-villages	A new urbanist concept in the idealistic peri-urban category, predicated on the virtues of dependable and frequent public transportation, a within-settlement energy efficiency, pedestrian accessibility, waste reduction reuse and recycling, food and fresh water quality and semi-sufficiency, all laced through with greenways and backgrounded by a farming-woodland landscape. In this context the eco-village construct reaches back into history by replicating the decentralized, away from the city yet locally concentrated, global-wide rural village pattern. It also attaches to the neomodern principles of *Agenda 21* – taking care of the community and the habitat. [Riddell 2004: 223-224]

Electric (battery) powered or assisted vehicles [EIA 2012]:

Full hybrid electric (HEV)	Vehicles that combine an internal combustion engine (ICE) with electric propulsion from an electric motor and battery.
Plug-in hybrid electric (PHEV)	Vehicles with larger batteries to provide power to drive the vehicle for some distance in charge-depleting mode, until a minimum level of battery power is reached (a “minimum state of charge”), at which point they operate on a mixture of battery and internal combustion power.
Plug-in electric (EV)	Vehicles that operate solely on an electric drivetrain with a large battery and electric motor and do not have an ICE to provide motive power. EVs are recharged primarily from the electrical grid by plugging into an electrical outlet, with some additional energy captured through regenerative braking.
Embodied energy	Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery. Embodied energy does not include the operation and disposal of the building material. This would be considered in a life cycle approach. Embodied energy is the ‘upstream’ or ‘front-end’ component of the lifecycle impact of a building.
Exurbs	The region surrounding an urban area, bounded at its outer edge by the limits of the commuter belt and at its inner edge by the limits of contiguous urban development. While being largely rural in appearance, it includes many people who are not involved in rural production, for example, commuters, the self-employed, retirees and second home owners. Such areas may also be referred to as *peri-urban*. [McKenzie 1996]
Global - globally	‘Pertaining to the whole world, world-wide’’. [Macquarie dictionary] *Globally* in the context of an oil-constrained future means that the extent of constraint is world-wide rather than merely local in its effect.
Green chemistry	‘The use of chemical techniques to reduce or eliminate feedstocks, products, by-products, solvents and reagents that are hazardous to human health and the environment’. [Wittcoff, Reuben & Plotkin 2004: 568]
Infill development	New development that occurs within established urban areas where the site or area is either vacant or has previously been used for another urban purpose. The scale of development can range from the creation of one additional residential lot to a major, mixed-use redevelopment. [Queensland Government 2009]

Life Cycle Assessment

Life Cycle Assessment (LCA) examines the total environmental impact of a material or product through every step of its life – from obtaining raw materials (for example, through mining or logging) all the way through manufacture, transport to a store, using it in a building and disposal or recycling.

LCA can consider a range of environmental impacts such as resource depletion, energy and water use, greenhouse emissions, waste generation and so on. LCA can be applied to a whole product (e.g. a house or apartment) or to an individual element or process included in that product. An internationally agreed standard (ISO 14040) defines standard LCA methodologies and protocols.

Natural Gas	Methane that has been processed to remove impurities to a required standard for consumer use. It may contain small amounts of ethane, propane, carbon dioxide and inert gases such as nitrogen. In Australia, natural gas comes from conventional gas and coal seam gas. Landfill and sewage gas are some other potential sources. [ABARES 2011]
Neighbourhood	This term is used to define 'a residential or mixed use area around which people can conveniently walk. Its scale is geared to pedestrian access and it is essentially a spatial construct, a place. It may or may not have clear edges. It may not necessarily be centred on local facilities, but it does have an identity which local people recognise and value'. [Barton 2000: 5]. For the purpose of this research, the neighbourhood is a functional entity, which may also be called a *residential precinct*.
New urbanism	An urban planning approach that promotes the creation of well-designed compact, walkable, mixed use neighbourhoods, towns or cities. New urbanism promotes diversity in land use and population, mixed housing and density, scaled for pedestrians, have a highly-interconnected street network capable of accommodating motor vehicles, cyclists and public transport and are designed with a high quality public realm.
Petroleum	Generic term for all hydrocarbon oils and gases, including refined petroleum products. [ABRES 2011]

Petroleum and other liquid hydrocarbons

The term "petroleum" refers to crude oil (including tight oil from shale [also referred to as shale oil], chalk, and other low-permeability formations), lease condensate, natural gas plant liquids, and refinery gain.

Petroleum inputs to urban development - for the purpose of this research:

<u>Primary</u>: The primary petroleum inputs to urban development are where refined oil fractions and petroleum gas (in liquefied or compressed gaseous states) are used *directly* as sources of fuel for transport, construction machinery and equipment, heating fuel and combustion processes (e.g. welding), lubricants, sealants and asphalt.

<u>Secondary</u>: The secondary petroleum inputs to urban development are where oil fractions and petroleum gas are used *indirectly* as feedstock for petro-chemical products (including adhesives, coatings, fibres, plastics, paints, resins and synthetic rubber); energy sources to manufacture construction and building materials, products and technology (*embodied energy*).

Peak oil	The event in time when oil production reaches its maximum annual rate, after which the annual production rate declines each year, with the result that growing demand cannot be met. Growth in global oil supplies has been sustained by expansions in supply from new oil fields. Eventually the rate of production decline at mature oil fields exceeds the rate of expansion at new oil fields and total world oil production will have peaked.
Petro chemicals	Petroleum and natural gas provide seven chemical building blocks on which the organic petro-chemical industry is based. The light and heavy naphtha

petroleum fractions are cracked to make gasoline (petrol) for transport fuel or to make olefins. The C3-C4 mixture is called liquefied petroleum gas (LPG) and may be used as a fuel or a chemical feedstock. Some ‘95% by weight of the organic chemicals the world uses come from Petroleum and natural gas’. [Wittcoff, Reuben & Plotkin 2004:57-61, 96]

Public-active transport oriented development (P-AMOD)
P-AMOD is suggested as a term to differentiate it from TOD. It would become a new standard for all urban precincts that goes beyond a nodal 400-800m TOD focus to align with the wider IRTP neighbourhood. The 1km /15 minute walking or 5 minute cycling radius places more emphasis on active transport and increases density gradients across the precinct.
See also Transit Oriented Development (TOD)

Resilient cities
For the purpose of this study: resilient cities have built-in systems that can adapt to change, such as a diversity of transport and land-use systems and multiple sources of renewable power that will allow a city to survive shortages in fuel supplies. [Newman, Beatley and Boyer 2009: 6]

Smart growth
A planning agenda that attempts to prevent urban sprawl. Smart growth requires a more efficient use of land by redeveloping older and under-used areas that are suitable and ready for renewal. [Duany, Speck & Lydon 2010]

Spatial (land use) planning
Spatial or land use planning is related to urban, regional and rural areas. The Planning Institute of Australia website offers one of several definitions:

Planning is the process of making decisions to guide future action. The planning profession (which is also referred to as ‘town planning’ or ‘spatial planning’) is specifically concerned with shaping cities, towns and regions by managing development, infrastructure and services. Balancing the built and natural environment, community needs, cultural significance, and economic sustainability, planners aim to improve our quality of life and create vibrant communities. [PIA 2010]

Suburb
Low density, urban development without systematic large-scale or regional public land-use planning. [Bruegmann 2005:18]. Suburban development is also associated with *urban sprawl*.

Sustainable development
In an urban planning context, this term refers to individual developments, movement systems and broader urban and energy systems that consume fewer resources, produce less waste and have a lesser impact on the earth’s ecological systems.

Transit
A term used to describe public transport, including bus, rail and ferry.

Transit corridor
An on-street transit lane or dedicated transit route that facilitates fast and frequent transit services along a corridor.

Transit nodes
Stations and focal points for transit services. Transit nodes tend to be well separated or less frequent to facilitate fast travel, as opposed to transit corridors, which provide frequent stops along a corridor.

Transit Oriented Development (TOD)
Transit oriented development is defined as a ‘mixed use residential and employment area designed to maximise the efficient use of land through high levels of access to public transport. A transit oriented development has a walking and cycle-friendly core with a rail or bus station, and is surrounded by relatively high density residential development, employment or mixed uses’. [SEQ Regional Plan pp101-103] TOD may also be called a *Transit Oriented Community* (TOC).

Transition Initiatives	A community led visioning process to lower energy consumption, increase resilience to energy shocks and climate change, simplify lifestyle and increase local sustainability, with local government support [Hopkins 2008]
Urban Form	Urban form is a set of complex relationships comprising: the development patterns and spatial structure in a hierarchy of scales (the urban fabric); the height, shape, density and appearance of the built environment; the interface between the built environment and public realm (streets and public spaces); movement hierarchies, networks and transport systems; public and private open space; developed within the historical, geographical, ecological and climatic context. [Author definition]
Urban metabolism	A model to analyse the flows of energy, water, food and materials into settlements and the waste outputs from them. It also encompasses the stocks of the natural and built environment and can be extended to human and eco-system services. [Yencken and Wilkinson 2000: 122]
Urban sprawl	Sprawl is a pattern of land use in an urbanized area that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. [Galster et al. 2001:681-709]
Urban structural unit	A morphological set of structured relationships between space, form and flows for an urban area of relative homogeneity with respect to the type, density and arrangement of built form and open spaces, which delineate a distinct configuration of the built environment [Osmond 2010: 9,18 Figure]
Urban village	A place within a city that has all the characteristics of a traditional self-contained village including a mix of land uses, high quality public transport, good urban design and attractive public spaces.

18 *The urban structural unit*

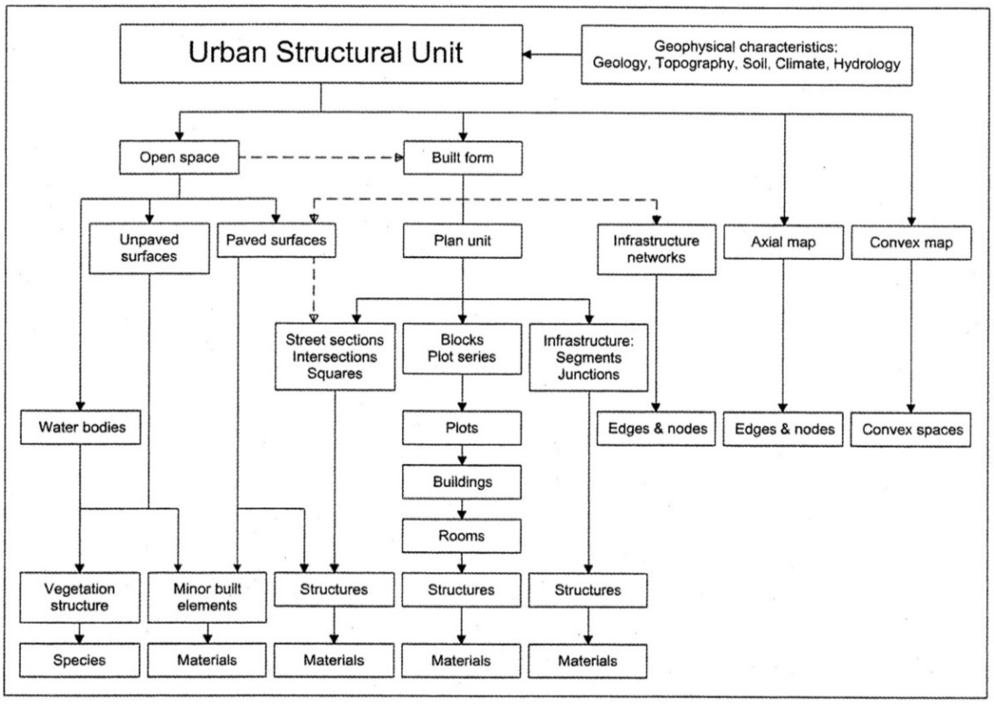

Figure 5. Decomposition of the urban structural unit. Continuous lines = distinct part-to-whole relations within hierarchies; broken lines = relations between separate hierarchies.

Urban Structural Unit : source Osmond (2010: 18)

Chapter 1

Introduction and research framework

> *We all want progress, but if you're on the wrong road, progress means doing an about-turn and walking back to the right road; in that case, the man who turns back soonest is the most progressive.* (C.S. Lewis n.d.)[1]

The world changed dramatically in 2008. The price of oil spiked to US $147 a barrel immediately prior to the world plunging into a multifaceted financial crisis (Rubin 2009: 17). A later consensus of views was that global conventional oil production had peaked, signalling the end of the era of 'cheap oil' (International Energy Agency (IEA) 2010: 6). The price of oil plummeted to US$40, but recovered to US$90-100 a barrel by late 2012[2]. The financial crisis lingered even in major countries, threatening several national economies and the continuing development of cities. In Australia, urban development languished despite efforts made by federal and state governments. It was a time of national reflection on our future directions with the development of a National Urban Policy (Australia 2010c, 2011). International forums continued debate about cooperative action and the role of renewable energy to replace coal and oil in mitigating climate change impacts (United Nations 2009b; 2015). This thesis will assert that the petroleum (oil and gas)[3] price volatility is an indication of an emerging *global wicked problem*[4] that will affect city growth.

This thesis arises from the author's stance as an Australian based environmental and urban planner, motivated to investigate the phenomenon of the likely effects of possible global conventional oil and gas supply depletion in relation to the sustainable growth of cities. The problem driving the research is enunciated as:

> Possible future oil constraints may affect urban residential development and hence the planning of sustainable urban forms in the context of a twentieth century Australian coastal city.

This research is directed towards the evolving urban forms of a coastal lifestyle-tourist city of 550,000 residents in the South East Queensland region of Australia. The Gold Coast was proclaimed a city in 1959 (Prideaux 2004) and is now the sixth largest

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1. C. S. Lewis. (n.d.). Retrieved April 9, 2013, from BrainyQuote.com: http://www.brainyquote.com/quotes/quotes/c/cslewis132782.html
2. The majority of this thesis was completed by December 2013. While the thesis was under examination and adjudication from 2014 to early 2016, the oil price plunged again to about $30 per barrel as low demand and geo-political forces manipulated the market and threatened the viability of the booming USA oil shale (tight oil) production (IEA 2015; Meiners et al. 2016).
3. Petroleum is the generic term for all hydrocarbon oils and gases (see glossary). In this thesis the focus is on the oil component, with inclusion of gas where appropriate, hence the more familiar and widely used term 'oil' is generally used for convenience.
4. Global wicked problems are defined and discussed in section 3.1.1 as being ill-defined, ambiguous and associated with strong moral, political and professional issues. Since they are stakeholder dependent, there is often little consensus about what the problem is, let alone how to resolve it (Tanter 2008). Such issues are suggested to be evident in the circumstances of 2014-16 oil supply manipulation.

in the country. While the Gold Coast is the focus of this thesis, the research has wide application to sustainable urban residential development planning in other cities.

This chapter overviews the research problem in a meta-level literature review; states the research questions, objectives and tentative propositions; establishes a conceptual framework and research design; sets the limitations and significance of the study; and outlines the thesis structure.

1.1 The research problem context

The twentieth century has been the era of abundant supplies of oil (petroleum) and the century of the motor car (automobile). Cheap petrol (gasoline) has been a significant catalyst for expansion of cities into suburbs (UN-Habitat 2009: 5), particularly in younger developed nations such as Australia, United States of America (USA), Canada and New Zealand, yet also in the United Kingdom, European and Asian nations. Newman and Kenworthy (1999: 101) have used multi-city comparative analysis to establish a strong link between urban density and private car usage in what they term the 'auto city'. The urban form of once compact cities has bloated into sprawling road and motor vehicle dominated metropolitan regions (Bruegmann 2005; Forster 2006: 17). City renewal has resulted in the gentrification and rising property values of inner and middle suburbs, resulting in issues of housing unaffordability and traffic congestion.

Modern cities are 'the products of the development of fossil fuel technologies' (Girardet 2008: 9). Oil has become fundamental to every facet of modern civilisation. Professor Peter Droege (2006: 160) contends that 'it is difficult to overstate the significance of black gold in defining virtually everything that cities are today: spatially, economically and culturally'. Oil geologist Professor Jeremy Leggett (2005: 21) asserts that 'we have allowed oil to become vital to virtually everything we do. Ninety per cent of all our transportation, whether by land, air or sea, is fuelled by oil'. In *Peak Everything*, Richard Heinberg (2007: 7) reminds us that 'for the past 200 years, cheap, abundant energy from fossil fuels has driven technological invention, increases in total and per capita resource extraction and consumption (including food production), and population growth'. The consensus is that the era of cheap oil is drawing to a close as global conventional oil production peaks, leading into a transition period of oil price vulnerability and gradual oil supply depletion, despite the short term supply of 'tight oil' by hydraulic fracturing methods (ASPO 2009; IEA 2010, 2015). Eventually, the oil-based economy that drives the modern world will falter, requiring a transition to energy based on renewable sources for sustainable urban development, with much greater emphasis on energy efficiency and conservation.

One of the consequences of oil combustion in all its forms and the resultant carbon dioxide (CO_2) emissions is its contribution to global warming and climate change. In a global perspective, Newman et al. (2009: 4) note that cities 'now consume 75% of the world's energy and emit 80% of the world's green-house gases'. While this is not all related to oil-based energy, transport alone accounts for between one-quarter and one-third of all energy consumption. The Intergovernmental Panel on Climate Change (IPCC) (2011: 10) estimates that in 2008 oil comprised 34.6 per cent of all energy sources in the total global primary energy supply. The IPCC 2007 report (IPCC 2007) highlighted the seriousness of climate change and the imperative to reduce global CO_2 production to limit average the global temperature rise to 2°C. The IPCC Assessment Report No 5, released in 2014, revises the 2007 predictions such that a range of 3-6°C by 2100 will be the more likely scenario, with more drastic consequences for the planet, based on the Working Group I report (IPCC 2013: 20).

These twin issues of oil supply depletion and climate change are thus seen as two of the key global problems of this century (Newman et al. 2009: 21), along with consequent food and water security. The critical importance of mitigating and adapting to climate change is acknowledged (e.g. Doucet 2007; Gleeson 2007; Brown 2008; CSIRO 2008; Garnaut 2008; Stern 2009; UN 2009a-c; IPCC 2013). Current research evidence indicates a widely held view that adapting to oil depletion will have a net positive benefit for climate change mitigation. This linkage is revisited in section 3.2 and relates the scope of this research on the issues of oil depletion to climate change mitigation and adaptation strategies.

Since the 1970s, the town planning and related professions have sought to control and manage the growth of cities to limit urban sprawl[5]. Local governments in Australian cities have developed planning schemes and, more recently, growth management strategies. Although such strategies introduce systematic land use regulations toward a more compact city form, suburban sprawl has continued in the spread of city footprints (e.g. Gold Coast City Council 2003; City of Sydney 2008; Western Australian Planning Commission 2010). Proactive government strategies anticipating an oil-constrained future are needed to drive transformation of urban design and ultimately, urban form.

Although local governments in Australia have favoured urban consolidation, a counter-culture to celebrate suburbs is typified by support from Troy (1996) and Stretton (1996). Davison (2006: 207-209) argues that the urban consolidation policies fuel a rhetoric of blaming suburban sprawl for the ‘many perceived environmental and social failings of suburbs’; overlooking the non-functional positive and practical values of suburbs ‘as places of emotional, moral and spiritual refuge’. Similar language is used in American studies such as *Superbia* (Chiras and Wann 2003) and *Don't Call it Sprawl* (Bogart 2006). These countervailing views are addressed in this thesis.

The conclusions inferred from and supported by many commentators are that oil supply vulnerability should be set within the bigger picture of ‘global wicked problem’ crises: climate change, resource depletion, food and water supply shortages, political upheaval (including Kunstler 2005; Brown 2006; Droege 2006; Gore 2006; Heinberg

5 For the purpose of this thesis, ‘sprawl’ is defined as low density, scattered, urban development without systematic large-scale or regional public land-use planning.’ Bruegmann (2005: 18).

2007; Greer 2008; Hopkins 2008; Newman et al. 2009; Rubin 2009). Failure to transition away from an oil-dependent economy is considered by some of these commentators to have the potential to cause a catastrophic breakdown of urban, and particularly suburban economic livelihoods and lifestyles in developed countries. Such cataclysmic worldviews are critically analysed in this thesis.

Since the early 2000s, planning research for climate change responses has started to evaluate the implications of oil depletion, mainly relating to private and public transportation and renewable energy in cities. Such planning responses also link to extensive guidance on adapting building design (green building) and energy conservation in cities (e.g. Anderson et al. 2002; US Green Building Council 2003 [LEED]; Lowe 2005; Droege 2006; CSIRO 2006, 2008; BRE 2009 [BREEAM]; Green Building Council of Australia 2009, 2010b). The voluntary 'green' rating schemes at the building scale are geared mainly to climate change mitigation and energy efficiency. While the underlying urban form provides the development and transport setting, the built environment is the product of contemporary technological design and construction processes, with varying quantities of renewable and non-renewable materials, each having different embodied energy (e.g. Australian Government 2008). These can be assessed through life cycle analysis of urban metabolic processes as elements of sustainable development theory (explained in sections 2.3 and 3.1). Ancillary transport issues are important, because oil–based transport is ubiquitous to land development and building construction from so-called cradle to completion, as explained in Chapter 3. However, there is an implied assumption in the reviewed planning studies that urban development will continue with a business as usual approach. Newman et al. (2009: 114) suggest that 'an analysis must be done of what it will take to change how we build and where and how people move around city regions'. Such an analysis should include how to continue residential land development and building construction with a modified approach for oil depletion and climate change.

One of the pathways to the oil-constrained future relies on technological solutions to maintain the status quo by exploiting unconventional sources of oil and gas, together with non-depleting energy sources, to meet future global demand for energy and petrochemicals. An alternative pathway—that could be termed a utopian 'yellow brick road' approach—may lead to transformation of cities to grow and function in a sustainable and regenerative manner with less dependency[6] on oil technology. The proposed research to investigate this problem is set out in the next section. The urgency of the research is highlighted by the premise that this future will evolve in the lifetime of the post-World War Two generations. Its importance is grounded in the knowledge that our grandchildren will live with the inter-generational consequences.

[6] 'Dependency' and 'dependence' are interrelated terms. Dependency implies a *state* of dependence, as in ongoing reliance on the functionality provided by an external agent or factor (http://wikidiff.com). This term is preferred in describing the dependency of urban development on the oil (petroleum) economy.

1.2 Research questions and objectives

The scope of this thesis outlined in section 1.1 focuses on the likely impacts of oil depletion on future urban forms in the context of Australian urban planning, and is related to a selected Australian major coastal urban area. The research approach developed in section 1.4 launches from a post-positivist ontological worldview to prefer a pragmatic stance (Johnson & Onwuegbuzie 2004, Morgan 2007, Creswell 2009). The research is necessarily limited in scope in order to be a feasible PhD study within time, resource limitations of a single researcher, cost and reporting constraints. The limitations of the research are described in section 1.5. This section sets out the thesis research questions and objectives.

1.2.1 Research questions to investigate the problem

The research problem introduced in the preamble and explicated in section 1.1 is that:

> ***Possible future oil constraints may affect urban residential development and hence the planning of sustainable urban forms in the context of a twentieth century Australian coastal city.***

The initial exploration of the problem context involved a process of data collection and analysis, inductively building from particulars to general themes and interpreting the meaning of the data (Creswell 2009: 4), to gain 'a better understanding of complex situations' (Leedy & Ormrod 2010: 95).

The research questions to address the problem have been delineated from this initial contextual analysis summarised in section 1.1, expressed in three linked parts:

Part 1. In the context of the growth of major Australian cities, what are the relationships between urban residential forms in the oil-based economy, and a future with constrained global oil supply?

Part 2. How might the land development and building construction factors; and the land use planning framework factors influence urban residential forms in the context of a selected Australian city?

Part 3. How might land use planning assist the transformation of urban residential forms in the selected Australian city towards an oil-constrained future?

1.2.2 Research objectives to investigate research questions

The objectives for each of the three questions is distinct and therefore may suggest different research approaches.

Research objectives for Part 1 research

The relationships between urban residential development and a future scenario with constrained oil supply are investigated through three related objectives to:

1.1 understand the context of Australian urban forms in the oil-based economy, including urban morphology and design, and sustainable city concepts

1.2 identify how oil-related issues are being addressed in urban growth management of major Australian cities, beyond the current climate change oriented responses

1.3 investigate the oil dependency relationships in urban residential development in the context of sustainability concepts, by reference to material and energy inputs.

Working propositions will be developed for objectives 1.1 and 1.2 at the end of Chapter 2 to determine oil dependency relationships. Objective 3 will be investigated in Chapter 3 to resolve the propositions in terms of the significance of such relationships.

Research objectives for Part 2 research

The relationships identified in Part 1 are investigated in relation to the Part 2 research in the context of a selected Australian city to:

2.1 identify the oil-related and planning-related factors that may affect the development and construction processes applicable to residential development

2.2 analyse the development and construction processes for a representative range of residential building typology to indicate the extent of vulnerability (if any) to future oil supply constraints.

The findings of the Part 2 empirical research in Chapters 4 and 5 are anticipated to confirm the Part 1 propositions and rather than forming new propositions, to provide inferences and constructs in relation to the above objectives, with which to develop insights, theoretical concepts and models in the Part 3 research using a new approach.

Research objectives for Part 3 research

The Part 3 research in Chapters 6-8 is anticipated to build on the Part 2 research findings to develop theoretical concepts and models that offer insight, enhance understanding, and provide a meaningful guide to action in the oil-constrained future scenarios. For the purpose of reporting the research on the problem, the following statements point towards the research tasks, although the theoretical concepts will actually emerge from the analysis (Suddaby 2006: 635, 637). In undertaking such a conceptualising methodology, these statements acknowledge the substantive existing empirical knowledge (Glaser & Strauss 1967: 79) to guide this analysis:

3.1 suggest relevant planning-related qualities and characteristics for oil-constrained cities, by drawing on values of pre-oil economy cities and experience of selected modern cities within a wider context of sustainable urban design

3.2 develop theoretical concepts and models about sustainable residential development in an oil-constrained future in the Australian urban context

3.3 demonstrate how land use planning can contribute to an orderly transformation of urban residential forms with reference to the selected Australian city.

Having defined the research questions arising from the contextual considerations of the thesis problem, and establishing the objectives for addressing those questions with some working propositions, the next step in section 1.3 is to develop an initial conceptual framework for the research. The second step in section 1.4 is to determine appropriate research methodologies that will implement the framework investigation.

1.3 Initial conceptual framework

This section provides a derivation of the initial conceptual framework for the thesis, building on relevant concepts, models and theories discovered through the preliminary literature investigation. That inquiry, explicated in section 2.3.1 of Chapter 2, suggests sustainable development theory, encompassing urban metabolism and sustainability science, provides a broad theoretical framework for this research.

1.3.1 Developing the conceptual framework

For the purpose of this thesis, sustainable development (SD) theory embraces many disciplines that address the environmental, economic and social aspects of development, including the concepts of urban metabolism and sustainability science (e.g. (Barton 2000; Neal 2003; Riddell 2004; Jenks & Dempsey 2005; Register 2006; Girardet 2008; Newman & Jennings 2008). SD is considered not to be an endpoint, but an integrated 'dynamic process of adaptation, learning and action. It is a complex concept with ecological, economic, geographical (spatial) and temporal dimensions—including inter-generational aspects—of the socio-economic system that embraces the concepts of land use planning and urban metabolism. More recently sustainability science (SS) has emerged out of the broad global change science domain, which integrates biological, geophysical, social (including economic) and technological research (Kates 2000: 1). Kates positions SS in the *pragmatic* theoretical perspective. All these strands are intertwined in the theoretical framework.

A theoretical framework is defined by Sekaran (2003: 97) as 'a logically developed, described and elaborated network of associations among the variables deemed relevant to the problem—identified through such processes as … literature review'. However, a distinction is made between a *theoretical framework* and a *conceptual framework*, although these terms are used interchangeably in theory literature (Chinn and Kramer 1999 cited in Liehr & Smith 2006, Jabareen 2009: 51). Liehr and Smith (2006: 12) suggest a theoretical framework is 'a structure of concepts which exists in the literature, a ready-made map for the study'; whereas a conceptual framework is 'a structure of concepts and/or theories which are pulled together as a map for the study' created by the researcher. A conceptual framework specifies what will be studied and describes in a narrative and graphical format 'the key factors, constructs and variables … and the presumed relationships between them' (Gray 2009: 174).

1.3.2 Urban metabolic conceptual model

This section outlines the urban metabolism model that is used to derive the conceptual framework for this thesis to explore the key relationships between oil-related inputs and urban development form. The conceptual framework for this thesis follows the above Liehr and Smith approach (2006: 12) and derives from two related models of the urban metabolism concept. In a study about sustainability of Australian settlements, Yencken and Wilkinson (2000: 120) suggest that 'settlements as they are usually conceived are inherently unsustainable'. This is partly because of the essentially linear movement of metabolic flows in and out of the urban system (albeit with increasing recycling of waste). The authors assess the issue using a conceptual framework at **Figure 1.1** adopted from the 1996 CSIRO State of the Environment Advisory Council (SOEAC) report (CSIRO Publishing 1996: 3-5). Yencken and Wilkinson analyse the flows of energy, water, food and materials into settlements and the waste outputs from them (2000: 130-36).

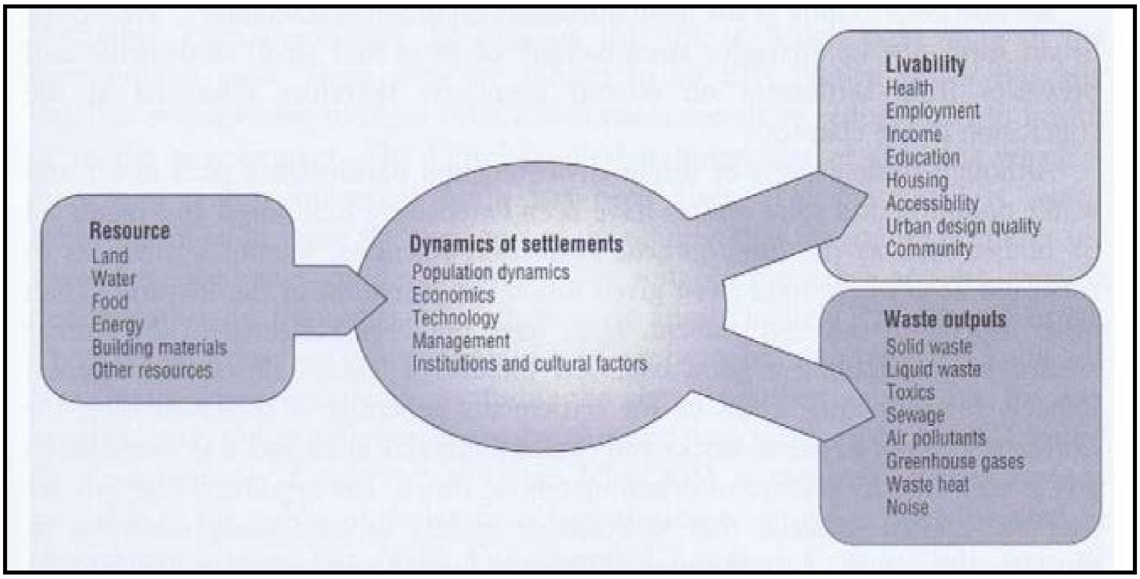


Figure 1.1: CSIRO extended metabolism model of human settlements

Source: CSIRO Publishing (1996: 3-5) (depicted in Yencken & Williamson 2000: 121)

This SOEAC based conceptual framework is a useful starting point for modelling the role of petroleum (oil and gas) in the urban ecology. It encompasses the inputs, stocks and outputs of the built environment and could be extended to human and eco-system services. Although only implied in the model, oil features in the resource inflows for energy, building materials and other resources. Its consumption also results in waste outputs, including liquid waste, air pollutants, greenhouse gases, waste heat and noise. However, these outputs are identified to be outside the scope of the thesis. The stocks or products of the oil-based economy are part of the settlement outcomes. They include the residential accommodation, community facilities, transportation and the infrastructure to support health, employment, education, and recreation activities depicted in Figure 1.1; together with land use planning and city management systems.

A second oil-specific conceptual model at **Figure 1.2** is a general metabolic city scenario derived in the thesis from the Yencken and Wilkinson model (2000: 121). Figure 1.2 indicates in *italics* the relevant oil related inflows and stocks to be investigated. It extends their model by highlighting the oil-based and oil-dependent metabolic inputs, and providing for reuse, recycling or recovery of oil-based materials from the waste stream. In this model, the focus of sustainable development would be to reduce input materials with high embodied energy and CO_2 production to decrease greenhouse gas emissions; reduce waste and maximise recycling and recovery. This simplified metabolic model forms the basis to explain the research problem relationships between the physical oil-related inputs and urban development.

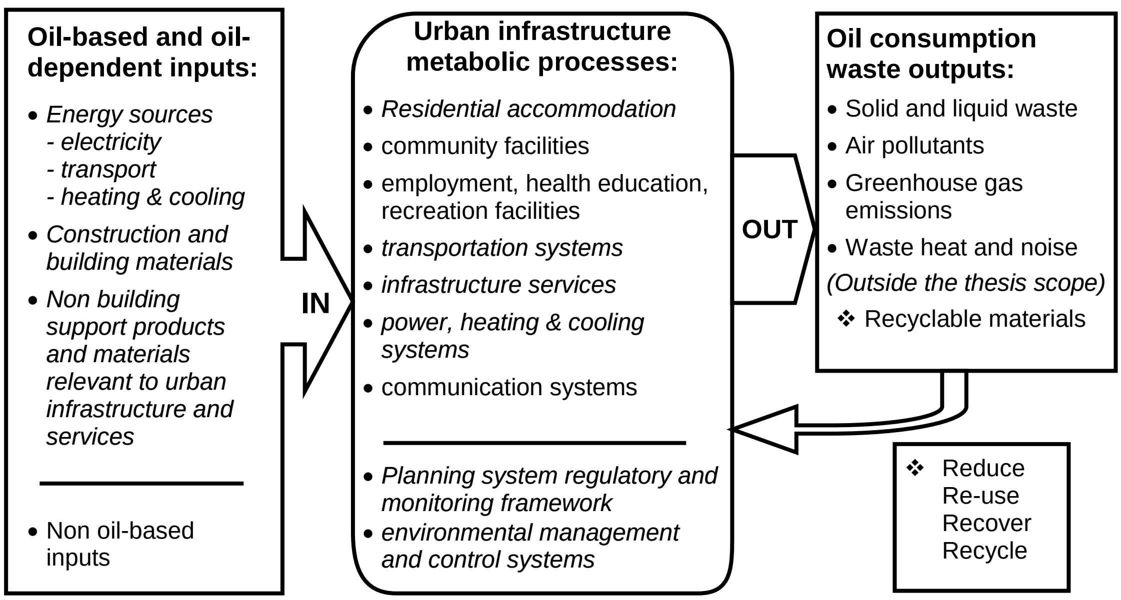


Figure 1.2: Oil-related urban metabolism model

Source: Adapted from Yencken and Williamson (2000: 130-36)

The third model at **Figure 1.3** is the ***initial conceptual framework*** devised for research into future changes in oil-related inputs that may influence urban form. It adapts the general metabolic relationship in Figure 1.2 to categorise oil-related input conditions, together with the planning-related social input factors, which affect urban residential development and urban form outcomes; as explained in section 1.3.3.

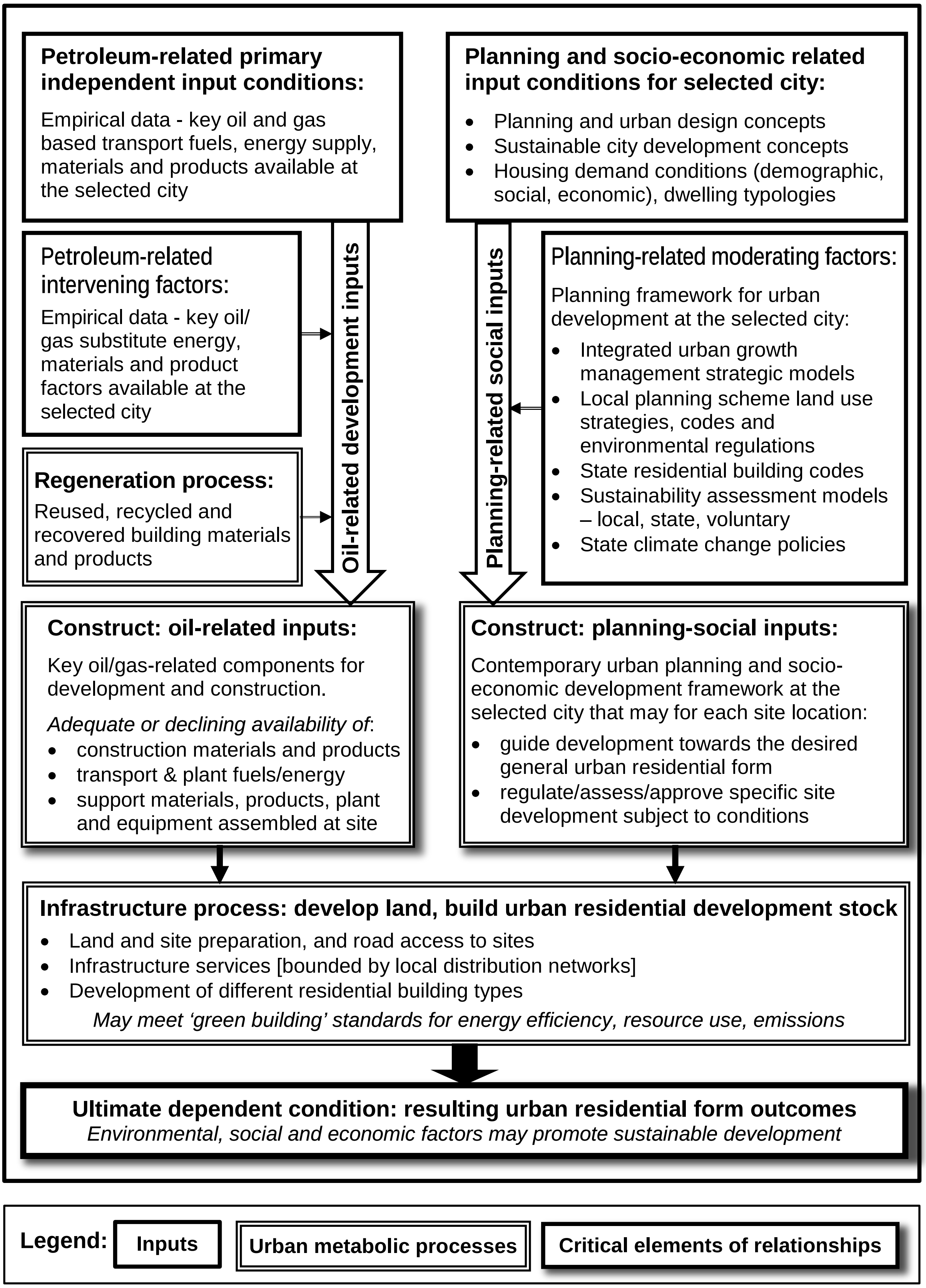


Figure 1.3: Initial conceptual framework for relationships between oil-related inputs to residential development and resulting urban form

Source: the author

1.3.3 Conceptual framework components

The main input conditions and concepts for the purpose of this thesis are restricted in scope to land development and building construction factors for urban residential accommodation, which may affect urban form outcomes. Socio-economic factors, upon which urban development is contingent in relation to market demand and finance, are important issues needing research beyond the scope of the thesis. The oil-related waste outputs identified in Figure 1.2 are also outside the scope of the thesis. The shadowed boxes in Figure 1.3 are critical elements of interest in the model relationships.

Input conditions

The input conditions described in Part 1 of this thesis include elements in the left-hand *oil-related development inputs stream* and the right-hand *planning-related social inputs stream* of Figure 1.3. Petroleum (oil and gas) related inputs are the primary independent factors as a sub-set of materials, components and energy flows—modified by intervening factors—that becomes a construct of physical inputs into the urban development applied to the selected city. The theoretical planning and urban design concepts, and the urban development factors determined by housing demand socio-economic conditions—modified by moderating factors—become a construct of policy framework inputs to plan and regulate urban development in the selected city.

Intervening and moderating factors

Sekaran (2003: 94) defines an intervening variable as 'one that surfaces between the time the independent variables start operating to influence the dependent variable and the time their impact is felt on it'. In the context of this framework model, the term 'variables' is replaced with 'factors' which has a similar meaning in qualitative research and the same principles apply (see section 1.4.2). The intervening factors are the substitute energy, materials and products available at the selected city; and the reused and recycled waste materials and by-products. Recycled waste components from regeneration processes would be supplied from oil-based materials and products. The independent and intervening components become physical inputs into the urban metabolic processes that produce development stock.

Sekaran (2003: 91) likewise defines a moderating variable as 'one that has a strong contingent effect on the independent variable–dependent variable relationship'. When the relationship is contingent or dependent upon another variable, the latter has a moderating influence. Unless the moderating variable is present the relationship cannot hold. In the context of this framework model, term 'variables' is again replaced with 'factors', hence the moderating factors are defined to comprise the planning system operating at the selected city including:

a. integrated urban growth management strategies in local planning instruments
b. planning scheme land use codes and environmental regulations
c. Queensland government residential building codes for sustainable development
d. sustainability assessment models and climate change policies.

Climate change planning responses unrelated to oil inputs are omitted from the scope of the thesis to limit the number of factors to be analysed in the Part 2 research.

Urban metabolic processes

In the context of this framework model, the metabolic processes that are central to producing urban residential development stock indicated in Figure 1.2 include land, building and infrastructure components including:

a. land and site preparation, and road access to sites
b. infrastructure services (bounded by local distribution networks)
c. construction of nominated examples of residential building types.

Such infrastructure may meet 'green building' standards and rating models for energy efficiency, resource use, greenhouse gas emissions. Hence there are multiple streams of potential metabolic outcomes in the urban stock ranging from minimal recognition of sustainable codes and practices to fully compliant infrastructure. Part 2 of this thesis research will demonstrate the metabolic process in a case study of four residential building typologies in the selected city context.

Ultimate dependent condition – urban form outcomes

The ultimate dependent condition is the urban form, which as noted above may or may not promote sustainable environmental, social and economic development outcomes. Part 3 of this thesis research will explore the key alternative pathways to more sustainable urban forms in an oil-constrained future.

1.4 Research methodologies for this thesis

This section develops the research methodology to investigate the research questions. The sustainable development and urban metabolism theoretical foundation underlying the conceptual framework in Figure 1.3 involve data that is both quantitative and qualitative in nature. The analysis of the data therefore requires consideration of both quantitative (deductive) and qualitative (inductive) research methodologies. How the inputs interact and influence the ultimate condition—urban residential form—will also have quantitative dimensions and qualitative characteristics, including temporal aspects as global oil supply varies in the future.

The research methodologies for each part are also distinctive because they serve a different purpose in addressing the objectives. Broadly the Part 1 investigative research into questions 1.1-1.3 establishes the urban development context and the dimensions of the oil dependency relationship. The Part 2 research into questions 2.1 and 2.2 follows the conceptual framework to investigate how the relationship is manifest in the selected Australian city. This leads into Part 3 question 3.1 to analyse how key qualities of recognised sustainable cities may be applicable to the selected city in the future; and question 3.2 to develop concepts, models and theories that refine the conceptual framework into a theoretical framework of the thesis problem.

Application of the derived theories to the selected Australian city in question 3.3 completes the thesis research and makes a contribution to knowledge of planning theory and practice. This methodology section has a structure of seven sub-sections:

1. Section 1.4.1 is a discussion of ontological and epistemological perspectives.
2. Section 1.4.2 surveys quantitative research methodologies, starting with a general description of experimental, survey and empirical research methods that may be applied to the problem, and suggesting relevant methods for this thesis.
3. Section 1.4.3 surveys qualitative research methods, starting with a description of ethnographic, grounded theory, case studies and phenomenological research methods that may be applied to the problem, and suggesting relevant methods for this thesis.
4. Section 1.4.4 discusses mixed methods pragmatic research that may be applied to the problem, including scenario theory, and suggests that this form allows for a richer data set and triangulation of data for the complex research of this thesis.
5. Section 1.4.5 discusses scenario planning as a mixed method methodology that is relevant to this thesis to create a story about some aspects of the perceived future.
6. Section 1.4.6 selects the research methodologies and describes their application to the research question objectives stated in sections 1.2.2 – 1.2.4.
7. Section 1.4.7 summarises the research design in tabular and graphic forms.

Appendix A sets out details of the selected methods, protocols and limitations in the research design, as well as definitions of relevant research methodology terms.

1.4.1 Alternative approaches to research methodology

The alternative theoretical perspectives and methodologies have been assessed by reference to Lewins (1992), Stake (1995), Strauss and Corbin (1998), Allmendinger (2002), Sekaran (2003), Glaser (2004), Pugh (2005), Bell (2005), Suddaby (2006), Johnson et al. (2006, 2007), Morgan (2007), Graziano and Raulin (2007), Babbie (2008), Creswell (2009), Gray (2009), Yin (2009) and Leedy and Ormrod (2010).

Ontological and epistemological perspectives–towards a pragmatic stance

In considering the appropriate research methodology, two basic paradigms have been relevant to choosing quantitative or qualitative oriented research. *Ontology* and *epistemology* describe two aspects of a system of beliefs in the philosophy of knowledge in viewing a problem in what Morgan calls the metaphysical paradigm (2007: 59). Ontology is the study of the nature of existence with two extremes—as an objective truth independent of the observer (realism); or the opposing view (nominalism) that no such ultimate reality exists and emphasises a changing and emergent world. Epistemology provides a philosophical background by trying to understand what a phenomenon means by deciding what kinds of knowledge about it are legitimate and adequate (Gray 2009: 17-18). The ontological realist view would regard oil supply as an objective finite resource, albeit with uncertainties about its full extent, and seek to compare the supply with demand in all its forms as a measure of the rate of consumption. If consumption outpaces supply, then the resource will decline at some measurable, though varying rate. The ontological nominalist view would suggest that while the phenomenon of oil supply may be an objective possibility, its supply limit is not proven and rate of consumption (and thus decline) is not at all predictable. This is evident in the USA oil shale hydraulic fracturing (fracking) technology), which has dramatically increased tight light oil production since mid- 2013. Moreover the government and private strategies for mitigating or adapting to oil depletion that address oil as a global wicked problem are subject to highly variable policy positions with winners and losers[7]. These aspects introduce *objectivist* (or positivist) and *constructivist* (or interpretivist) epistemological approaches explained below. An objectivist approach would lead toward quantitative methodologies to investigate oil production statistics to establish empirically derived limits. A constructivist approach would lead to gaining a better understanding of the drivers for oil demand and the potential responses to oil depletion by more qualitative methods.

However, research theory development has moved a long way in the last decade or so from the debates over positivism as the dominant theoretical perspective about the realist nature of reality (Allmendinger 2002: 77; Gray 2009: 19). 'A post-positivist domination of planning theory in recent years has rightly highlighted the social and political context of the theories … through various guises including collaborative, post-modern and [neo-] pragmatic approaches' (Allmendinger 2002: 77). Morgan 2007: 60) asserts that 'we are currently in the midst of a new paradigm shift that will replace the metaphysical paradigm as a dominant belief system … just as it replaced positivism'. *Pragmatism* is therefore an alternative epistemology that removes strict distinctions between quantitative or qualitative oriented research (e.g. Allmendinger 2002, Johnson & Onwuegbuzie 2004, Morgan 2007, Creswell 2009). This alternative approach combines both methodologies; however all three approaches are addressed to select the best approach to the types of evidence being gathered and how to interpret them.

1.4.2 Quantitative approaches to research methodology

Quantitative research has been the traditional method used for scientific or empirical research (Creswell 2009: 4). This approach comes from an objectivist or positivist epistemological view that holds 'a deterministic philosophy in which causes probably determine effects or outcomes' Creswell (2009: 7). It relies on objective observation and measurement by examining the relationships between independent and dependent *variables*[8]. to test a theory or hypothesis in a deductive approach, so as to explain a situation or understand a problem. These variables typically can be measured so that

[7] This is also evident in the geo-political manoeuvring by OPEC members since 2014 (after completion of this thesis) to reduce competition by driving down oil prices to around US$30 per barrel (ASPO 2015).

[8] See Appendix A definitions for comparative description of variables and factors.

numerical data can be analysed using statistical procedures. A key aspect is for other researchers to be able to replicate the tests to verify the results of such analysis. It is the intent to seek explanations that will generalise to other situations or places, so as to contribute to existing theories (Leedy & Ormrod 2010: 95).

The scientific method is also subject to theory dependency—'the influence of certain often unstated assumptions on the research process' (Lewins 1992: 9)—where it is essential that 'assumptions' and 'objectivity' are free of researcher bias. In the case of this research, underlying assumptions about the 'essential nature' of oil supply and demand could be open to challenge, because current or future technological advances (e.g. the USA oil shale fracking technology) may provide adequate or even superior substitutes (the nominalist ontological position and constructivist epistemological approach). At the same time there may be biases, for example in reporting of reserves by oil producers that also distort reality. The associated quantitative research strategies are suggested by Creswell (2009: 12) to include:

a. <u>Experimental research</u> – conducting experiments with fixed control of treatment conditions to determine the outcome of a specific treatment of independent variables on dependent variables (considered relevant to this thesis).
b. <u>Survey research</u> – 'providing a quantitative or numeric description of (generally) trends, attitudes and opinions of a population by studying a sample of that population' (not considered relevant to this thesis).
c. <u>Empirical observation</u> added by Graziano and Raulin (2007: 12) – gaining knowledge through direct observation to recognise and record factual events – for inference and inductive reasoning (considered relevant to this thesis).

The Part 2 research involves both an objectivist and a constructivist epistemological approach to determining how the land development, building construction and the land use planning framework factors might influence urban residential forms. The urban metabolism model and life cycle analysis introduced in this chapter and applied in Chapter 3 are clearly forms of empirical observation and research based on a theoretical framework, wherein the causes probably determine effects or outcomes. A partial life cycle analysis in the form of a material flow analysis could be used to identify and quantify the oil related inputs to urban residential development. The model treatment conditions would be bounded by the input processes to create the site and building stock. The consumption of oil-based materials and energy could be quantified at a range of scales from a selected city down to site level. However, while the data exists independently, the socio-economic factors and the political-planning context are relevant and point to evaluating the variables as *factors* in a post-positivist approach without manipulating the data using a statistical method.

The oil-related inputs to residential development are quantifiable on a site basis up to whole city scale, given sufficient resources for the research. Assessing the impacts of oil depletion introduces qualitative value judgments about assumptions. Hence the choice of materials and energy forms at all scales also has a constructivist element, because value judgments are needed in the use of alternative non-oil related materials or energy in particular projects. A site-based analysis of representative examples of residential development using experiments with fixed control of treatment conditions could be appropriate to the scope of this thesis, to demonstrate the oil-based inputs.

Conclusions on quantitative research

The conclusions from this overview of quantitative research methodology are that:

a. The initial literature investigation has revealed the urban metabolism model is a suitable theoretical framework within which to undertake quantitative research.
b. A post-positivist empirical quantitative research approach could be a suitable tool to investigate Part 2 objective 2.1 on the intervening factors.
c. The application of the urban metabolic research approach is suitable to analyse inputs of oil-related materials and products and related components using material flow analysis, described in Appendix A, and based on:
    - multiple secondary data sources
    - supplementary observational data.
d. A form of experimental research could be suitable to investigate Part 2 objective 2.2 on the residential land development, building construction and ancillary transport factors in the context of the selected Australian city.
e. These quantitative methods need to be complemented by qualitative methods in assessing objectives 2.1 and 2.2, which makes alternative approaches a necessary consideration.

1.4.3 Qualitative approaches to research methodology

Qualitative research 'is exploratory, and researchers use it to explore a topic when the variables and theory base are unknown' Creswell (2009: 98). Although Creswell uses the example of 'urban sprawl' as a problem needing to be explored, most of the authors cited in this section relate qualitative methodologies to sociological, health and psychological research, which requires caution in adapting to the planning field. Allmendinger (2002: 82) points out that the shift to a post-positivist perspective 'has, in part, led to a plethora of theoretical positions' in planning that embrace social and historical contexts in 'practical "real world" situations as a social construction' (2002: 87). The associated qualitative research techniques typically involve emerging questions and procedures, data collection and analysis; with the researcher interpreting the meaning of the data to inductively build from particulars to general themes or theories (Creswell 2009: 4). Such inductive techniques develop *propositions* that may be supported, rather than testing a *hypothesis* in a deductive approach (see Appendix A definitions). Leedy and Ormrod (2010: 95) extend this approach to 'seeking a better understanding of complex situations'. Such an approach is relevant to making sense of the data collected in a so-called 'evidence based' planning paradigm.

Strauss and Corbin (1998: 10) define qualitative research broadly to mean 'any type of research that produces findings not arrived at by statistical procedures or other means of quantification'. This does not preclude quantifying of qualitative data, but rather has the intent of discovering concepts and relationships in the raw data (that may include census data) so as to explore areas about which little is known. The associated qualitative research strategies of inquiry include:

a. Ethnography – a longitudinal study of a cultural group in a natural setting (Creswell 2009: 13)—not considered relevant to this thesis.
b. Grounded theory – a generally inductive approach to theory development 'that is discovered, developed and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon' (Strauss and Corbin 1998: 23)—considered possibly relevant to this thesis.
c. Case studies - a study exploring 'in depth a program, event, activity, process, individual or group' to collect detailed information for analysis (Creswell 2009: 13; see also Yin 2009 below). This may involve analysis of documentary data, which may include descriptive (nominal or ordinal) or quantifiable (interval or ratio) data to draw inferences and theoretical concepts, but not establish causes—considered relevant to this thesis.
d. Phenomenological research - a strategy to identify 'the essence of human experiences about a phenomenon as described by participants' (Creswell 2009: 13). This can use a survey, interview, or documentary research approach—it is considered to be only partially relevant to this thesis (because a preliminary pilot survey of awareness and meaning of peak oil issues revealed such little relevant information as to be of no value. However, focused interviews with planning experts as participants could verify provisional theories.)

Grounded theory

Strauss and Corbin (1998: 12) refer to grounded theory (GT) as meaning 'theory that was derived from data, systematically gathered and analyzed through the research process'. The researcher begins the process with no preconceived theory in mind and allows the theory to emerge from a data categorisation process, using constant comparison and theoretical sampling methods. Grounded theories 'are likely to offer insight, enhance understanding and provide a meaningful guide to action' (Strauss & Corbin 1998: 12). Because of increasingly varying interpretations of the methodology confusing it with qualitative data analysis, the joint originator Barney Glaser reminds us that 'classic GT is simply a set of integrated conceptual hypotheses systematically generated to produce an inductive theory about a substantive area' (2004: 2). He goes on to assert that the data collection and analysis should *not* start with a preconceived problem, as is the case with this thesis. Yet Gray (2009: 502) considers the research 'should commence with a defined purpose, and also the realization that this purpose may become modified or even radically altered during the research process itself'. In a review of misconceptions about GT, Suddaby (2006: 634) makes a similar claim that even GT should start with a clear research question and acknowledge existing empirical knowledge, including substantive theory. He suggests that the temptation to test hypotheses can be avoided partly by drawing on several substantive areas, and by being 'aware of the possibility that you are being influenced by preexisting conceptualizations of your subject area'. He adds that researchers 'may shoot for "the elaboration of existing theory" rather than untethered "new" theory' (2006: 635). However, Suddaby cautions that it is less appropriate 'to use grounded theory when you seek to make knowledge claims about an objective reality' (2006: 634). Other reviews of GT highlight not only the growing schism between the positions of Glaser and Strauss (e.g. Richardson & Kramer 2006: 498; Suddaby 2006: 638), but also the central role of abduction as 'the process of studying facts and devising a theory to explain them' (Cunningham, 1998: 833). Within the GT approach, Richardson and Kramer (2006: 500) quote Coffey and Atkinson (1996: 155) as recognising the importance of abduction by stating that 'abductive reasoning lies at the heart of "grounded theorizing"' and that 'abduction is a type of inference that operates 'bottom up': individual facts are collected and connected together in order to develop hypotheses'. The process of abduction is revisited in the following section on pragmatic mixed methods.

Noting Suddaby's caution on knowledge claims about an objective reality, the general GT process does not align well to investigate Part 1 of the research problem, which is proposed as an exploratory literature review of existing empirical knowledge to develop propositions (rather than testable hypotheses) about the significance of the relationship of oil inputs to urban development. However, application of grounded theory is very well suited to Part 3 objectives to investigate sustainable planning responses to oil constraints and develop a meaningful guide to adaptive action. An alternative phenomenological inductive methodology could be useful in objective 3.2 to support GT in developing models and theories about sustainable residential urban development. Inductive logic would build on this base to derive theory (as sets of concepts for prediction) about the contribution of land use planning to improve the transformation of urban residential forms to an oil-constrained future.

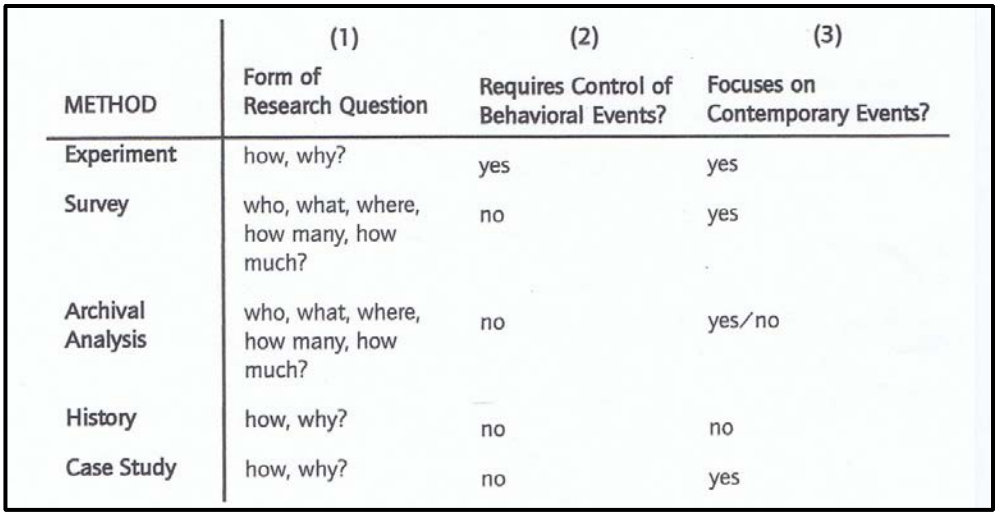
Case study analysis

The aim of case study analysis in qualitative research, according to Stake (1995: 37), is to understand the complex interrelationships among all the factors involved in the research question, as a phenomenological study. This view is supported by Yin, who suggests 'the distinctive need for case studies arises out if the desire to understand complex [social] phenomena' to answer the 'how' and 'why' questions relative to explaining contemporary events (Yin 2009: 4). This is particularly relevant to cases where the behaviours cannot be manipulated by the observer, which is pertinent to this research. In the context of research methods for construction, Fellows and Liu (2008: 23) suggest the use of case study methods to 'demonstrate particular facets of the topic, or to show the spectrum of alternatives'. A case site-based study of representative examples of residential development therefore would be appropriate to the scope of this thesis, to demonstrate the oil-based inputs.

A combination of a variety of data collection methods, including surveys, is useful to 'address more complicated research questions and collect a richer and stronger array of evidence than can be accomplished by any single method alone' (Yin 2009: 63). In order to decide whether a case study or other approach is appropriate Yin (2009: 8) gives a typology of qualitative research methodologies based on the presence, or not, of three conditions and the appropriate research methods:

1. the form of research question being investigated
2. whether the investigator can exercise control of the actual events
3. whether the focus is on contemporary or historical events.

The relevant situations are illustrated by Yin at Figure 1.1 (2009: 8) and reproduced at **Figure 1.4**. It classifies five research methods to answer a particular form of the three conditions. Yin notes that the classification boundaries are not sharp, but will assist in selecting the most appropriate method for the exploratory, descriptive, or explanatory purposes of the research. Every method can be used for all three purposes.



METHOD	(1) Form of Research Question	(2) Requires Control of Behavioral Events?	(3) Focuses on Contemporary Events?
Experiment	how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Archival Analysis	who, what, where, how many, how much?	no	yes/no
History	how, why?	no	no
Case Study	how, why?	no	yes

Figure 1.4: Relevant situations for different research methods

Source Yin (2009: 8)

Conclusions on qualitative research

Application of the criteria suggested in Figure 1.4 to this research confirms that:

a. The investigator has no control over actual events (relevant to four methods).
b. The focus is mainly on contemporary and future events.
c. Research objective 1.1 is based on a combination of the 'what', 'where', 'how' and 'why' forms in an historical, contemporary and theoretical overview of the context of Australian urban forms. (This suggests an exploratory and explanatory archival (documentary) analysis method).
d. Research objective 1.2 is based on a combination of 'what', 'where' and 'how' forms to investigate *how oil-related issues are being addressed in urban growth*

management of major Australian cities. (This suggests a combined descriptive, exploratory and explanatory documentary method).

e. Research objective 1.3 is based on a combination of the 'what', 'where' and 'how much' forms to investigate *the oil dependency relationships in urban residential development.* (This suggests a descriptive documentary analysis method).

f. Research objective 2.1 is based on a combination of the 'what', 'where', 'how much' and 'why' forms to *identify the oil-related and planning-related factors that may affect the development and construction processes applicable to residential* development. (This suggests a descriptive documentary analysis method).

g. Research objective 2.2 is a 'what' and 'how' form, leading into a consideration of 'why' to analyse *the development and construction processes for a representative range of residential building typology to indicate the extent of vulnerability (if any) to future oil supply constraints.* (This suggests an empirical comparative case study based on quantitative analysis, with an explanatory element.

h. Research objective 3.1 is a mixed 'what', 'how' and 'why' form, to *suggest relevant planning-related qualities and characteristics for oil-constrained cities* (suggesting a combined descriptive and explanatory abductive analysis method).

i. Research objective 3.2 is a combined 'how' and 'why' form, to *develop theoretical concepts and models about sustainable residential development in an oil-constrained future in the Australian urban context. (*This suggests a grounded theory development method building on objective 3.1 is most appropriate).

j. Research objective 3.3 is a 'what' and 'how' form to *demonstrate how land use planning can contribute to an orderly transformation of urban residential forms with reference to the selected Australian city.* (This suggests a descriptive method).

The conclusions from the discussion on qualitative research methodology are that:

a. <u>archival (documentary) analysis</u> would be useful to investigate part of research objectives 1.3 and 2.1

b. a <u>case study method</u> is suitable to investigate research objective 2.2 in combination with quantitative experimental methods

c. the <u>grounded theory method</u> is very well suited to research objectives 3.1 and 3.2 to construct models and theories about sustainable residential development in the oil-constrained future; with application of grounded theory to objective 3.3.

d. an <u>interview research method</u> would be useful to investigate part of research objective 3.2 as a limited phenomenological research strategy to verify the theoretical concepts, leading to grounded theory development.

1.4.4 Pragmatic mixed methods approach to research methodology

The use of *mixed methods* expresses a world view of *pragmatism* (e.g. Creswell 1998, Patton 2002, Johnson & Onwuegbuzie 2006, Morgan 2007). Creswell acknowledges there are many forms of pragmatism: 'a philosophy arising out of actions, situations and consequences rather than antecedent conditions (as in post-positivism) (Creswell

2009: 231). He suggests that 'pragmatism is not committed to any one system of philosophy and reality'. Pragmatist researchers do not see the world as an absolute unity, but look to the 'what' and 'how' to research based on the intended consequences – the use of the results (Tashakkori & Teddlie 1998, Patton 2002).

Mixed methods research is 'an approach to inquiry that combines or associates both qualitative and quantitative forms' (Creswell 2009: 4). It may use both approaches concurrently or sequentially to gather and analyse data, give a priority, and involve the integration of the data at one of more stages of the study. Morgan calls this a version of *abductive* reasoning—'first converting observations into theories and then assessing those theories through action (2007: 71). This form allows for a richer data set and triangulation of data collection and analysis to gain a more valid outcome than using only one method alone. In summary, 'abduction creates, deduction explicates, and induction verifies' (Yu 1994). These characteristics and flexibility are persuasive in adopting the approach to the research methodology for the complex research of this thesis as multiple types of data and analysis are needed in each part of the research questions to discover a valid outcome.

1.4.5 Scenario planning methodology

Scenario planning is a mixed method methodology that is relevant to this thesis to create a story about some aspects of the perceived future. Futurist Herman Kahn first defined scenario planning as ''a set of hypothetical events set in the future constructed to clarify a possible chain of causal events as well as their decision points'' (Kahn & Wiener 1967). Scenarios are also defined as alternative futures resulting from a combination of trends and policies (Fontela & Hingel 1993: 139-154). It is suggested that 'in the present era characterized by uncertainty, innovation and change, increasing emphasis is being placed on the use of scenario planning techniques because of its usefulness in times of uncertainty and complexity' (Schoemaker 1991: 549). A paper in Futures Journal presented by Amer et al. claims as at 2012 to be the first 'to review and summarize the scenario validation criteria presented in literature' in detail (Amer et al. 2013: 38). In classifying scenario planning methods, the authors note (2013: 25) that futurist 'Dator's work on his alternative futures approach articulates four scenario archetypes', of which the transformation scenario fits into this thesis:

> *'Continued growth: In this future, it is assumed that current conditions and trends are enhanced.*
>
> *Collapse: This future results as continued growth fails and there are great contradictions.*
>
> *Steady state: This future seeks to arrest growth and find a balance in the economy and* with nature. It highlights a balanced, softer and fairer society.
>
> *Transformation*: This future tries to change the basic assumptions of the other three. It comes out either through dramatic technological change or [societal] change.'
>
> (Amer et al. 2013: 25)

There are three general approaches to create a robust number of scenarios: minimal (2), standard (3-8) and maximum (>8). The minimal approach uses two key drivers to create scenarios, but requires great care to choose appropriate factors that are sufficiently different from one another to generate a strategic conversation (Curry & Schultz 2009). This approach may be adequate to illustrate the transformative scenario for an oil constrained future as applied to the selected city. In creating valid scenarios for this purpose, Van der Heijden (1996) identifies five criteria, which are in general agreement with other authors (cited in Amer, Daim & Jetter 2013: 36):

- ‘At least two scenarios are needed to reflect uncertainty
- Each scenario must be plausible
- Scenarios must be internally consistent
- Each scenario must be relevant to the client’s concern
- Scenarios must produce a new and original perspective on the issues’

1.4.6 Selection of methodologies and research design

The three general methodologies using quantitative, qualitative and mixed methods approaches have value and relevance, but point towards a preference for the combined mixed methods approach that draws on the relevant attributes of each one. Creswell (2009: 15) summarises the methods (**Table 1.1**). Therefore a pragmatic epistemological approach is adopted, using mixed methods and abductive research processes, in which facts are collected and connected together in order to develop hypotheses and theory about the implications of a possible oil-constrained future for urban residential development and urban form. The thesis research design combines the methods in the following ways for each research question.

Table 1.1: Comparison of quantitative, qualitative and mixed methods

Table 1.3 Quantitative, Mixed, and Qualitative Methods

Quantitative Methods →	Mixed Methods	← Qualitative Methods
• Pre-determined • Instrument based questions • Performance data, attitude data, observational data, and census data • Statistical analysis • Statistical interpretation	• Both pre-determined and emerging methods • Both open- and closed-ended questions • Multiple forms of data drawing on all possibilities • Statistical and text analysis • Across databases interpretation	• Emerging methods • Open-ended questions • Interview data, observation data, document data, and audio-visual data • Text and image analysis • Themes, patterns interpretation

Source: Creswell (2009: 15)

Part 1 research methods

Part 1 investigates the Australian urban development context; relevant sustainable planning theories; and relationships between urban residential development and a future with a constrained oil supply, through three related objectives.

Research objectives 1.1 and 1.2

1.1 Understand the context of Australian urban forms in the oil-based economy, including urban morphology and design, and sustainable city concepts

1.2 identify how oil-related issues are being addressed in urban growth management of major Australian cities, beyond the current climate change oriented responses.

The approach to investigate the Part 1 research objectives 1.1 and 1.2 employs qualitative combined descriptive, exploratory literature review and documentary methods, in which the empirical data gathering involves an inductive process of data and theoretical analysis. Chapter 2 investigates these objectives with a view to suggesting one or more working propositions about relationships between urban residential development and oil dependency in a selected Australian coastal city.

Research objective 1.3

1.3 Investigate the oil dependency relationships in urban residential development in the context of sustainability concepts, by reference to material and energy inputs.

The research for objective 1.3 in Chapter 3 uses a combination of qualitative descriptive documentary analysis informing post-positivist empirical research in a mixed methods approach to investigate the oil dependency relationships in urban development. The empirical research method uses urban metabolism theory and life cycle theory to identify the key oil and gas inputs to develop working propositions about the significance of the oil dependency relationships. How the key material flow analysis terms are defined and applied to this research, and the protocol to be followed, are set out in **Appendix A**. The empirical data for oil and gas related inputs are presented in descriptive and tabular form in **Appendix B** (located in the CDROM).

The Part 1 research in Chapter 3 will resolve support for the working propositions developed in Chapter 2 to determine whether a significant relationship exists between new urban residential development and future oil supply constraints.

Part 2 research methods

Part 2 research investigates the land development, building construction and ancillary transport factors; and the land use planning related regulatory framework factors to examine the significance aspect of Part 1 propositions, and provide inferences and constructs about urban residential forms to inform the Part 3 research.

Research objective 2.1

2.1 Identify the oil-related and planning-related factors that may affect the development and construction processes applicable to residential development.

The approach selected to investigate research objective 2.1 is a qualitative descriptive documentary analysis in Chapter 4, informed by the findings of objective 1.3 of:

a. substitute materials and energy as intervening factors at the reference city
b. state government regional and local planning framework moderating factors:
    - the state planning policy and regional planning framework
    - relevant building-related regulations
    - relevant local government planning scheme provisions
c. sustainable assessment and climate change moderating factors
d. overview of the legislative reform program in the Queensland planning system.

Research objective 2.2

2.2 Analyse development and construction processes for a representative range of residential building typology to indicate the extent of vulnerability to future oil supply constraints.

A comparative pilot case study method is selected to investigate research objective 2.2, based on empirical quasi-experimental methods. The case studies in Chapter 5 analyse oil-related inputs using a partial material flow analysis for a representative residential building typology in the reference city selected in section 2.2 of Chapter 2; the study case criteria and protocols to be followed are set out in **Appendix A**. The protocol for phenomenological focused interviews with the case study development companies and their consultants to verify data on oil-based and substitute materials and products; and essential related components, equipment and processes is also set out in **Appendix A**. Tables of embodied energy indices are set out in **Appendix C** for the benefit of the reader. Detailed data for the four cases are set out in **Appendices D** to **G.** Appendices B to G and additional material are in the CDROM enclosed with the thesis.

Part 3 research methods

The Part 2 research findings are anticipated to provide inferences and constructs to develop into theories in Part 3 that offer insight, enhance understanding, and provide a meaningful guide to action in the oil-constrained future.

Research objective 3.1

3.1 Suggest relevant planning-related qualities and characteristics for oil-constrained cities, by drawing on values of pre-oil economy cities and the experience of modern cities within a wider context of sustainable urban design.

The approach selected to investigate research objective 3.1 in Chapter 6 is a grounded theory investigative approach using an abductive analysis method. The method develops insights by drawing on the pilot case studies, relevant values of sustainable design for urban residential forms exemplified in pre-oil economy cities and the more recent experience of nominated modern cities. The insights within the wider urban context may be applicable to the selected Australian coastal reference city to suggest qualities and characteristics for oil-constrained cities, as propositions to inform theory research for objective 3.2 in Chapter 7.

Research objective 3.2

3.2 Develop theoretical concepts and models about sustainable residential development in the oil-constrained future in the Australian urban context.

The approach selected to investigate research objective 3.2 in Chapter 7 is abductive analysis using the grounded theory method on collected documentary data, case studies, substantive insights and propositions from objective 3.1. The aim is to develop conceptual hypotheses generated inductively to produce theories, concepts and models to explain how planning can assist sustainable residential development in an oil-constrained future in the Australian urban context. The theory analysis is verified by a phenomenological research method using focused interviews with experts in the planning and development sectors to assess the hypotheses and suggest theories. The grounded theories will be used to refine an integrated conceptual framework.

Research objective 3.3

3.3 Demonstrate how land use planning can contribute to an orderly transformation of urban residential forms with reference to the selected Australian city

The grounded theories and integrated conceptual framework will be applied in Chapter 8 to demonstrate possible planning outcomes. A scenario planning method illustrates possible adaptive and maladaptive planning outcomes in the transitional period and an oil-constrained future; and to suggest planning guidance applicable to other cities.

1.4.7 Research design summary

The research design is summarised in **Table 1.2** to show the above research objective methodologies explicitly, and **Figure 1.5** shows the overall structure. The detailed procedures and protocols for the conduct of the research are at **Appendix A**.

Table 1.2: Summary of mixed research methodologies for thesis

Research objective	Chap.	Methodology
1.1 – 1.2	2	Qualitative combined descriptive, exploratory and explanatory documentary methods to establish oil dependency relationship
1.3	3	Qualitative descriptive documentary analysis informing post-positivist empirical research in a mixed methods approach to investigate the oil dependency relationships
	3	Urban metabolism theory and life cycle theory to identify the key oil and gas inputs and establish oil dependency significance
2.1	4	Qualitative descriptive documentary analysis
2.2	5	Comparative pilot case study method based on empirical methods
3.1	6	Grounded theory investigative approach using abductive analysis
3.2	7	Grounded theory abductive analysis using the collected documentary data, case studies, and objective 3.1 insights and propositions to derive theories and refined conceptual framework
3.3	8	Apply grounded theories and a refined integrated conceptual framework to the reference city in a scenario approach.

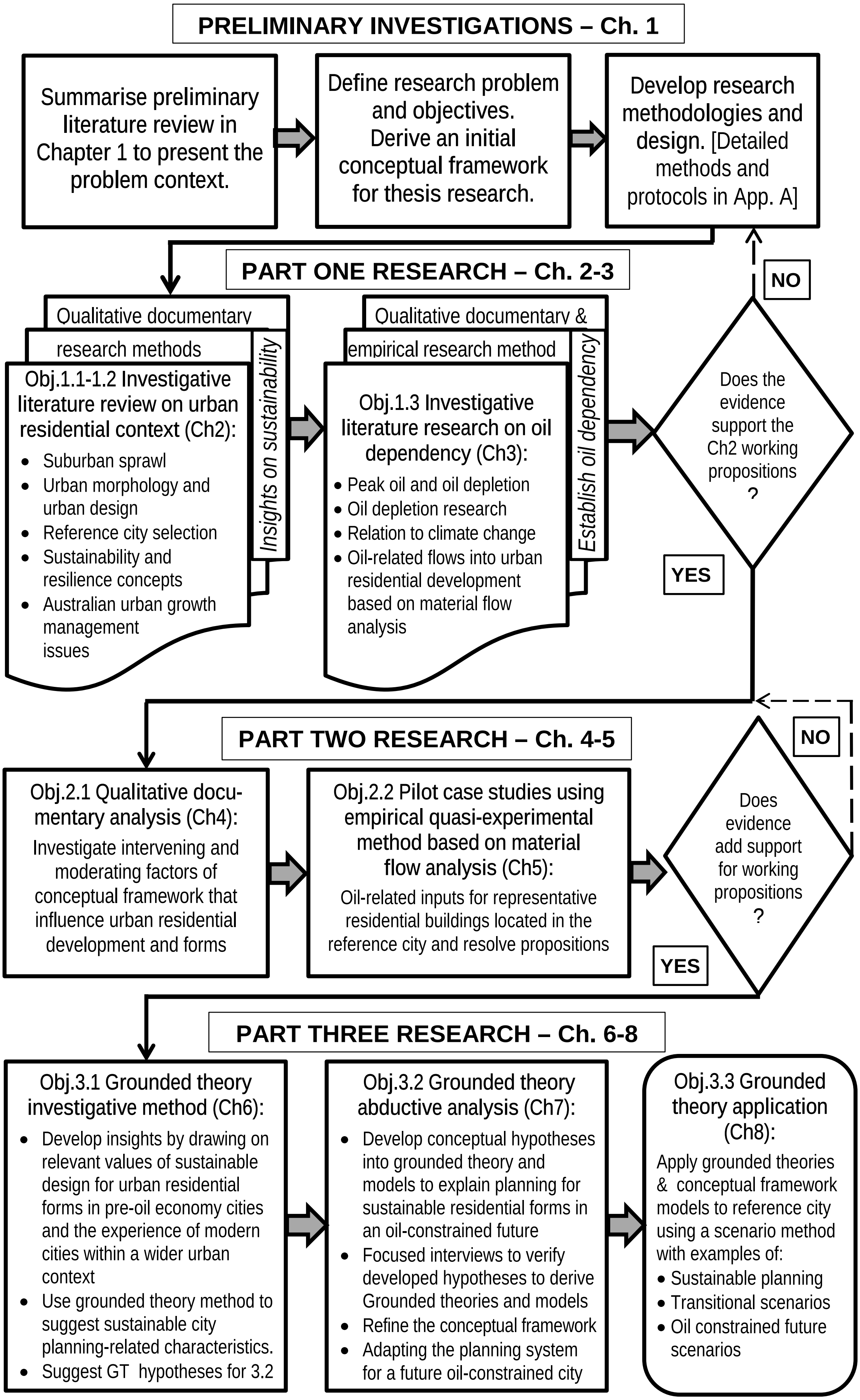


Figure 1.5: Research design summary

1.5 Research limitations

The wide range of the topic necessitates limiting the research to a manageable scope for the purpose of a PhD thesis by research. The thesis is not attempting to produce an exhaustive catalogue of the contribution of petroleum (oil and gas) to the modern city as part of the urban metabolism, described in Chapter 3. Rather the aim is to examine the inputs of petroleum in its broad sense—as a fuel and as a feedstock to make products—in facilitating urban residential development; and to assess the potential influence on future urban form mainly in the Australian context. The research is therefore circumscribed spatially and by exclusion of life cycle considerations of emissions to air, water and land; the maintenance, repair and eventual demolition of buildings. Operational and transport energy are excluded as being well researched.

The case studies are pilot phase assessments, utilising the documentary bills of quantity sources for representative residential building types. Two cases are presented in depth – the detached house and the six storey medium-rise apartment building. Two other cases are presented in less detail to analyse the differences in construction. The qualitative nature of the research and small sample limits statistical analysis of the data.

The use of alternative building construction materials, which are less dependent on the oil economy, may have greater or lesser durability (e.g. clay based masonry, cob, or timber). Less durable materials may require more maintenance and will need repair or replacement at an earlier time, if that is even feasible within the building fabric (Roaf 2007; Spence & Kultermann 2011). Decisions to use non-durable material with short life cycles could prove to be poor investment strategies. Use of expensive construction and finishing materials adversely affects housing affordability, but may improve durability. The life cycle impacts of alternative construction, as well as operational energy and end of use options have been evaluated in other research (e.g. Anderson et al. 2002; Thormark 2002; Pears 2005; Sobotka & Rolak 2009; Crawford 2011).

The research is also circumscribed by excluding the impacts of oil depletion on the actual construction and operation of motorised vehicles. A conservative assumption is made that vehicles involved in the development and construction industries could still be made using some form of renewable energy source. However, the operation of such vehicles will depend essentially upon alternative energy sources. Estimates could be made in relation to current on-site construction vehicles, by reference to site logs and vehicle operation costing records (if any). Such vehicle data is irrelevant in relation to future operation, without sophisticated consideration of alternative fuel (or battery electric power) availability and the modus operandi of trucking operators.

A difficult research task for the purpose of this thesis is to calculate the vehicle kilometres travelled by construction workers, without making gross assumptions about journeys to work sites. Likewise the trip lengths of vehicles used in material distribution is conjectural. Workforce transport is addressed by qualitative description to highlight the issue. The increasing cost of travel to work sites is considered to be relevant, unless sites are on public transport routes – for instance construction along a transit corridor. It is also relevant that trades workers traditionally carry their own equipment and tools to more than one construction site, making the use of public transport unviable. Workforce transport practices may need to change radically in the oil-constrained future and some options are explored in the thesis.

Planning scheme provisions may act as barriers unless appropriate changes are made to facilitate adaptation to the oil-constrained future. The review and analysis of potential barriers to adaptation in the case studies context is based on the City of Gold Coast planning scheme (GCCC 2003), as regulated by existing and proposed state planning legislation, other state planning instruments and the South East Queensland (SEQ) Regional Plan (Queensland 2009). While the thesis discusses potential limitations in the Queensland context in relation to state policies and local government planning schemes, the state planning is in a state of transition under planning reforms commenced in 2012, but not completed by late 2015[9]. Other jurisdictions have similar frameworks for land use planning, which points towards further research on oil depletion transition strategies in all jurisdictions in Australia and elsewhere.

1.6 Anticipated significance of the research

The anticipated significance of the research, given its limitations outlined above, is the contribution of knowledge towards extending sustainable development planning theory and practice, relevant to urban residential forms in an oil-constrained future. Land use planning is expected to contribute to an orderly transformation to an oil-constrained future by improving the resilience of urban residential forms, and by anticipating the future in advocating less vulnerable development and more structured redevelopment. This thesis is therefore broadly based in a sustainable development theoretical framework, as embracing urban resilience and extending to transformation and regeneration.

Analysis of the research questions will be developed into working grounded theories. Sustainable future urban residential forms will require achievement of four key elements: urban fabric and housing that reduces oil dependency; energy efficient building systems adaptable to change; low energy mobility in its widest sense; and efficient urban metabolism that includes multiple sources of renewable power and transport energy. The contributions are anticipated in the findings of the various case studies in the thesis that inform the development of grounded theory; applied to an integrated conceptual framework and models for sustainable land use planning policies. The thesis aims to demonstrate such planning policies and strategies to adapt urban residential development to the impacts of oil depletion. A scenario planning method will be applied to the Queensland City of Gold Coast. The contributions have potential for general application in the wider Australian context and in similar western type cities.

[9] Queensland planning reform is overviewed in chapter 4, but since the thesis was submitted in early 2014, a second change of state government has delayed and reoriented the process.

1.7 Thesis structure

This final section outlines the structure of the thesis. It broadly follows the pattern suggested by Patrick Dunleavy (2003: 60), which 'has been successfully applied in the humanities and social sciences' and is illustrated in **Figure 1.6**. The general structure between the introductory and concluding chapters is to have a focused literature review in one main chapter containing materials that readers need to know; core material on the detailed research; followed by opening out into analysis and discussion. Dunleavy suggests considering whether a separate chapter on methodology should be included in the main sequence of the argument at all. He considers that it 'is often best to write a special "Research Methods Appendix" to come *after* the main set of chapters. It can be written as a reference material annex, which allows you to include very detailed information for examiners and fellow researchers, but without disrupting the development of your main argument' (2003: 61). This structure allows the core research to come earlier in the argument and results in a nine chapter thesis, plus appendices. In this thesis, chapter 2 focuses on the underlying literature review, which also develops some analysis. Chapters 3-5 form the core research material. Chapters 6 and 7 contain the grounded theory abductive analysis, with application in chapter 8.

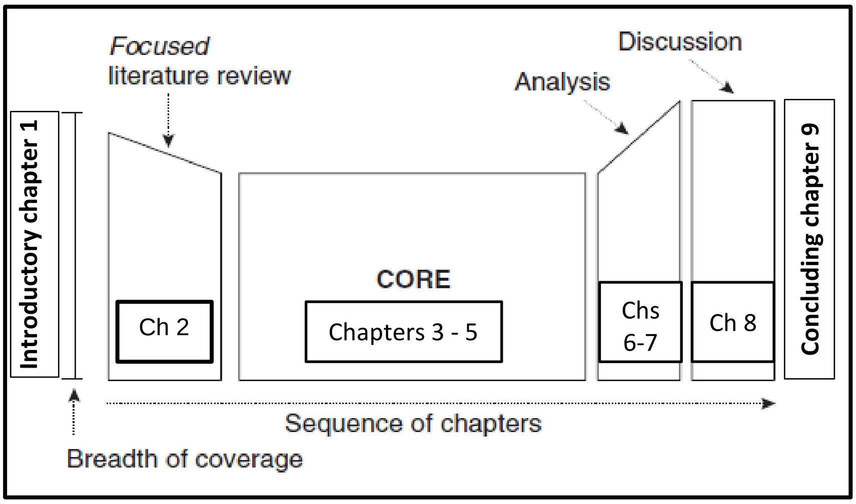


Figure 1.6: General model of the thesis structure

Source: After Dunleavy (2003: 61)

Chapter summaries

Chapter 1 introduces the urban development–oil dependency relationship research problem and sets out the research questions and objectives. It develops an initial conceptual framework. The research methodology to address the research question objectives and the selection of a mixed methods approach shows how the thesis research is structured. The limitations of the research and anticipated significance of the thesis are stated. The chapter is supported by Appendix A, which describes the research design methods, procedures and protocols. Appendices B-H are in the CDROM.

Chapter 2 addresses research objectives 1.1 and 1.2 in a focused investigative literature review to establish the urban development context and what characterises the urban form of major Australian cities. The rationale is provided for selecting the reference City of Gold Coast. The underlying morphology and urban design theory, and the concepts of sustainable development are analysed for relevance to the problem. A review of growth management in three major Australian cities includes the reference city.

Chapter 3 addresses research objective 1.3 by focusing on the details of urban residential development dependency in relation to oil. Oil dependency is presented as a global wicked problem. The timing of peak oil supply and the implications of oil depletion expounded in current research are addressed. The relationship between oil consumption and climate change as twin global problems is analysed. Key oil and gas inputs are described using material flow analysis to identify building materials stocks and flows of energy, to determine the extent of oil dependency in residential building development. This chapter is supported by Appendix B (CDROM) detailing the oil inputs.

Chapter 4 investigates research objective 2.1 by analysing the intervening factors of substitute materials and energy that could be relevant to adapting development to an oil-constrained future. The state and local land use planning related regulatory factors are analysed in the context of the City of Gold Coast for their potential as facilitators of, or barriers to, adapting urban residential forms to oil constraints. The chapter overviews an ongoing Queensland planning reform process, which is yet to be finalised.

Chapter 5 investigates research objective 2.2 using empirical comparative pilot case studies that apply the material flow analysis to nominated residential building types in the selected City of Gold Coast. Oil and gas-related inputs are compared for each case type to determine the relative vulnerability between types from cross-case analysis. This chapter is supported by Appendices C to G that contain the detailed analysis.

Chapter 6 explores research objective 3.1 by drawing on the relevant values of sustainable design for urban residential forms, exemplified in pre-oil economy cities and in the experience of nominated modern cities within a wider urban context. These values suggest characteristics for oil-constrained cities that may be applicable to the City of Gold Coast. Four working propositions are developed for grounded theory analysis.

Chapter 7 addresses research objective 3.2 using abductive analysis of the objective 3.1 propositions to derive grounded theories that are developed into an integrated theoretical framework for sustainable urban forms in the Australian city context. The analysis is supported by focused interviews with experts in the planning sector to verify the developed theories for adaptation strategies in an oil-constrained future.

Chapter 8 applies the integrated theoretical framework and the adjusted land use planning policies to objective 3.3, relating to the City of Gold Coast. A scenario approach is used to demonstrate possible adaptive and maladaptive planning outcomes.

Chapter 9 draws together the research findings pointing towards the oil-constrained city of the future. Conclusions are made about the potential impacts of oil depletion on urban residential forms. The chapter reflects on the thesis and attests the contributions to planning theory and practice, both in the Australian and potentially wider context. Suggestions are made for ongoing research in this field.

The thesis structure is illustrated in the chapter map at **Figure 1.7**

Chapter 1: Introduction and research framework

1.1 The research problem context
1.2 Research questions and objectives
1.3 Initial conceptual framework
1.4 Research methodologies
1.5 Research limitations
1.6 Anticipated significance of the research
1.7 Thesis structure.

Appendix A
Detailed research methods and protocols

PART 1 RESEARCH OBJECTIVES 1.1 – 1.3

[1.1-1.2] **Chapter 2: Australian urban residential development context**

2.1 Urban residential development context.
2.2 Reference city selection
2.3 Urban form and concepts of sustainable development
2.4 Australian urban growth management
2.5 Conclusions on urban growth context

[1.3] **Chapter 3: Dependency of urban development on petroleum**

3.1 Oil dependency and peak oil
3.2 Oil depletion and climate change
3.3 Oil-related flows to urban residential development
3.4 Conclusion: dependency of cities on oil is significant

Appendix B: Oil and gas inputs (in CDROM)

PART 2 RESEARCH OBJECTIVES 2.1 – 2.2

[2.1] **Chapter 4: Intervening and moderating factors for development**

4.1 Intervening factors for oil-related inputs
4.2 Moderating factors for urban development
4.3 Queensland planning system reforms
4.4 Conclusions on the development and planning factors analysis

[2.2] **Chapter 5: Pilot case studies**

5.1 Study cases and strategy
5.2 Pilot case study A – single level detached house
5.3 Pilot case study B – low rise apartment building
5.4 Pilot case study C – medium rise apartments
5.5 Pilot case study D – high rise apartment tower
5.6 Cross-case comparison
5.7 Case study conclusions

Appendices C – G (in CDROM

PART 3 RESEARCH OBJECTIVES 3.1 – 3.3

[3.1] **Chapter 6: In search of the sustainable city**

6.1 Qualities of pre-oil economy cities
6.2 Qualities of sustainable cities
6.3 Characteristics of oil-constrained sustainable cities
6.4 Conclusions on oil-constrained sustainable cities

[3.2] **Chapter 7: Oil-constrained sustainable urban residential forms**

7.1 Development of grounded theories and models
7.2 Focused interviews to verify grounded theory concepts
7.3 Grounded theories and integrated conceptual framework
7.4 Conclusions on oil-constrained residential urban forms

Appendix H: Queensland's planning system in an oil-constrained future (in CDROM)

[3.3] **Chapter 8: Gold Coast oil-constrained future urban forms**

8.1 Application of grounded theories to City of Gold Coast
8.2 Sustainable planning models
8.3 Towards the transitional city of tomorrow
8.4 Towards the oil-constrained city of the future
8.5 Conclusions on the oil-constrained city

Chapter 9: Thesis conclusion: towards the oil-constrained city

9.1 Findings of the research and grounded theory relevance
9.2 Toward the cities of tomorrow and the oil-constrained future
9.3 Contributions to sustainable planning theory and practice
9.4 Recommendations for further research

Figure 1.7: Thesis chapter map

(Parts 1 and 3 are shaded for clarity)

Part 1 Research

Australian urban residential development: dependency on petroleum

This part of the thesis, consisting of Chapters 2 and 3, presents the context pertaining to residential development in major Australian cities, and the arguments establishing the dependency relationships with petroleum. The research approach for objectives 1.1–1.3 is shown in the research design map extract at **Figure A**. Chapter 2 is an investigative literature review that addresses research objectives 1.1 and 1.2 of research question 1 on how urban residential development and consequential urban form may relate to oil dependency and possible future oil depletion. The literature review findings are further investigated in Chapter 3 to address research objective 1.3 by determining the significance of the dependency relationships of urban residential development to petroleum (oil and gas). The chapters are important in demonstrating the extent of oil dependency as an emerging global wicked problem; the global peak of conventional oil production and timing, and key implications of oil depletion for urban development. The urban metabolism theory used as the theoretical basis to develop the conceptual framework in Chapter 1 is applied with material flow (life cycle) analysis to provide a description of the oil and gas inputs, the details of which are in Appendix B (in CDROM). The chapters refine a proposition for further testing in the Part 2 research.

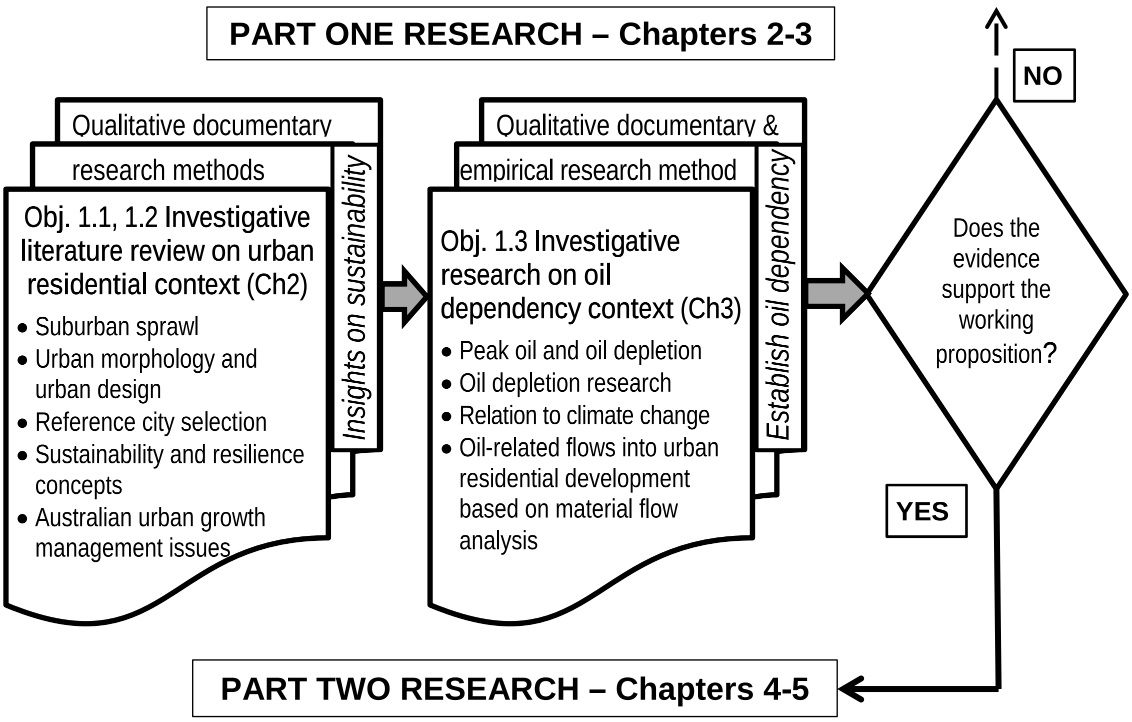


Figure A: Part 1 research design summary

Chapter 2

Australian urban residential development context

Prediction is very difficult, especially about the future. (Niels Bohr: n.d.)

The focus of this chapter is to investigate objectives 1.1 and 1.2 in research question 1, with the aim of forming working propositions on how oil dependence and possible future oil depletion may relate to sustainable development and construction factors in urban residential development and consequently on urban form. The exploratory literature research investigates relationships between sustainable urban residential development and a future globally constrained oil (petroleum) supply in the Australian urban growth context, encompassing the following aspects:

1. *Urban Development Context*: An overview of urban growth patterns and urban form, highlighting urban sprawl as a phenomenon of twentieth-century oil fuelled private car transportation, with a brief introduction to urban morphology and urban design to establish the theoretical planning framework;

2. *Reference city context*: selection of an Australian city as the reference case study city and for application of concepts and theoretical constructs for sustainable future development in an oil-constrained future.

3. *Sustainable city and related concepts*: An overview of sustainability theory and resilience concepts from an ecological sustainability and transformative viewpoint to demonstrate how evolving sustainable development theory relates to future urban growth management.

4. *Urban growth issues*: Future urban growth management using recent studies and strategies, evidencing a transition toward planning policies for more sustainable urban forms; how oil-related issues are being addressed beyond the current climate change related responses.

The review does not investigate in detail the passenger transport related impacts of oil depletion, because these aspects have been well researched in many studies relevant to the Australian context, which draw on and also inform international studies (including Newman & Kenworthy 1999; Diesendorf 2000; Yencken & Wilkinson 2000; Glazebrook 2003; Forster 2004; Yanuaria 2004; Yigitcanlar et al. 2005; Droege 2006; Dodson & Sipe 2006, 2008b; Harris 2007; Queensland Government 2007a, 2009c; Waller 2008; Adams 2009; Newman et al. 2009; Weller et al. 2009). However, the transport element is taken into account in the overall sustainability assessment.

2.1 Urban residential development context

This section will demonstrate by literature review and documentary research that in the Australian context, suburban expansion has been at the heart of urban growth in major cities. This context is important to understand the relevance and implications of oil dependency and what oil depletion might mean for sustainable cities in the future.

2.1.1 Urban development and sprawl

In his compact history of sprawl, Robert Bruegmann (2005) charts the progress of suburbs in Europe and USA from the Roman period to the present. Indeed the term 'suburb' comes from the Roman word *suburbium* as 'the area below or outside the city walls' (Bruegmann 2005: 23). In such areas were mixed land uses that could not be accommodated within the confines of the compact, defensible and walkable enclaves of the densely built city environment. Suburbs not only accommodated the poor citizens and industry, but also were home to the most affluent, evidenced by elegant villas in the hills east of Rome (2005: 23). Prior to the motor car era, however, cities were essentially walkable enclaves, albeit with horse-drawn carriage transport, and historically within a protective wall. In the twentieth-century inter-war years, an acceleration of outward movement of both residential and industrial development led to an explosion of the urban land areas in Australian, American and northern European cities as part of the phenomenon termed 'urban sprawl'. The relevance to this study of the exposition by Bruegmann (and other authors cited below) is that suburban expansion has driven urban growth in Australian cities. A survey of suburban history and urban sustainability by Aidan Davison (2006: 202-205) remarkably finds:

> [T]he 1891 census revealed Australia to be not only the second most urbanised land on earth (next to Britain), but the most suburbanised of all. Not only were Australian colonies leading the race to become suburban, however, they were experimenting with the very form, function and meaning of the city … [C]apitals developed suburbs before their centres were built up.

In the USA context Rowe (1991) and Bruegmann (2005) suggest that the expansion of the vast highway system facilitated outward movement to the low density suburbs and beyond them the semi-rural 'exurbs', as well as development of suburban shopping malls. By the end of the 1930s, 'the outlines of the multi-nucleated city, with its adjacent suburban and exurban zones that we usually associate with the post-war era, were already in place' (Bruegmann 2005: 38). Bruegmann acknowledges the difficulty in defining sprawl. He concludes from his extensive research (2005: 231) that while it has been the subject of measuring quantifiable parameters and relationships—such as density, continuity, concentration, clustering, centrality, mixed uses and proximity, as proposed by Galster et al. (2001)—'it has been the non-measurable, especially aesthetic, aspects of sprawl that have constituted the emotional heart of the debate on the subject'. Bruegmann (2005: 18) defines sprawl in simpler, qualitative terms: ‘sprawl is low density, scattered, urban development without systematic large-scale or regional public land-use planning’. In the Australian context, however, the low density suburbs are in fact planned as greenfield development in zoning plans. Bruegmann argues that later gentrification of the historic core of cities led to a bi-directional flow of people. Many neighbourhoods were changing in ways not explained by simplistic static snapshot models of dynamic urban form and growth, such as the 1923 Park and Burgess model of Chicago, the modified Hoyt’s 1939 sector diagram, or the Harris and Ullman 1945 Multiple Nuclei model, shown at **Figure 2.1** below.

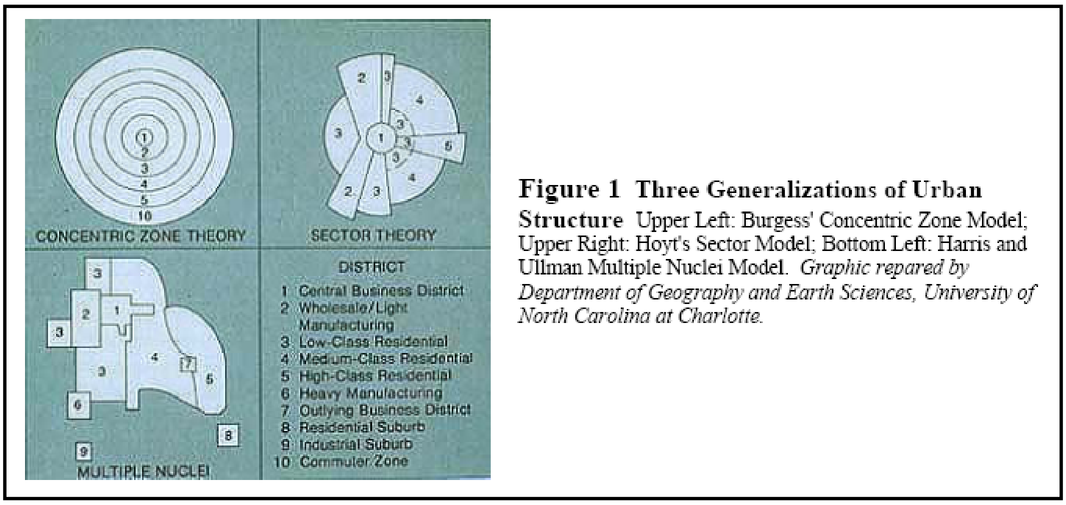


Figure 2.1: Three 20th century generalizations of urban structure - Park and Burgess model, Hoyt sector model, Harris & Ullman multiple nuclei model

Source: Campbell, H.S. Jr (1998)

A particular feature of Hoyt’s sector model was the apparent influence of rail and tram transit routes in the gradual outward residential and manufacturing extension along such corridors. Public transit serviced corridors also allowed and facilitated a bi-directional flow of people. This contrasted with the ill-defined form of the multiple nuclei model, which reflected the transition from walking and transit cities to what Newman and Kenworthy term the ‘auto city’ (1999: 31). Of course these idealised models of a single city could not speak for all western cities. The point being made here is that they represent three definite generalised patterns of urban growth that have become a part of the planning lexicon. Added to these types is a linear urban pattern with a dumbbell, or string of pearls arrangement (Cervero 1998: 6), especially where villages and towns coalesce into metropolitan cities such as at the coastal City of Gold Coast, Queensland (Figure 2.4). The polycentric form is a modern variant of the multiple nuclei model (Davoudi 2002: 3).

The freedom of the private car led to an infilling between rail and tram routes, indicated as districts *4* and *5* in both models, extending urbanisation for those who could afford such personal mobility to some fifty kilometres—about thirty minutes driving time—from the employment heart shown as districts *1* and *2*. Low class residential districts *3* remained in closer proximity to employment centres or transit routes. Hence low density suburban sprawl was a significant heritage of the motor car in the auto city. Davison suggests 'the creation of suburbs was a defining preoccupation of Australian society' in the twentieth-century, and during that period the capital cities' suburban population grew from less than one million to over 11 million (Davison 2006: 207). During the post-war period from 1945 to 1975, private car ownership 'accelerated the centrifugal forces' in city expansion and 'suburban homes were transformed from self-contained productive sites ... into places for consumption'. The theme of the auto city presented by Newman and Kenworthy (1999) is also taken up by Clive Forster (2004: 17) in his study of the Australian urban form. The transformation from the star-shaped public transport (transit) based city 'with its "arms" of residential development extending along the tram and train tracks, radiating from a dominating city centre' to the amorphous multi-nuclei form of the auto city, was clearly apparent by the 1960s and is reproduced in **Figure 2.2**. A linear form also facilitates efficient public transport systems, until development away from the axis changes it into an amorphous form, such as occurred at the Gold Coast (Figure 2.4).

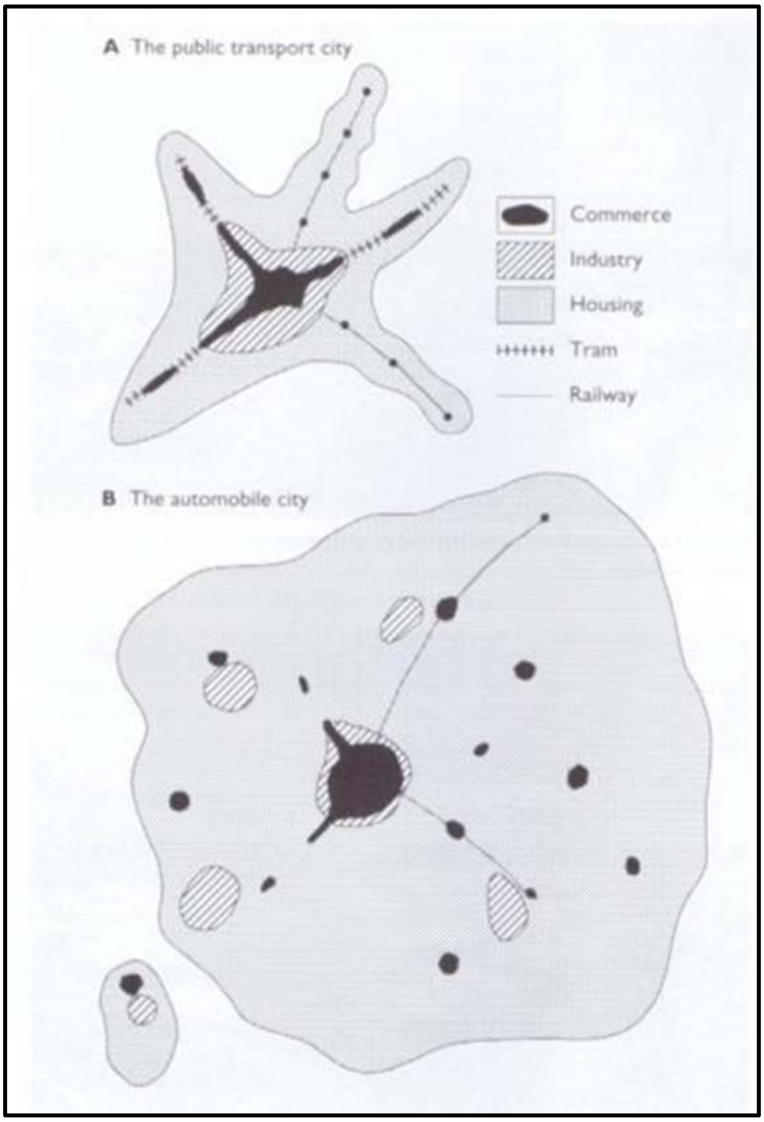


Figure 2.2: Transformation of the transit city (A) into an auto city urban form (B)

Source: Forster (2004: 20)

Figure 2.2 diagrammatically indicates also the demise of tram routes in cities (with the notable exceptions of Melbourne, and Adelaide Glenelg route), which were superseded by bus–based public transportation. Forster (2004: 18) notes ‘only cars could connect low-density suburban homes to jobs, schools, universities, health services, and entertainment venues that were themselves increasingly located in other suburban locations, served poorly, if at all, by public transport’. Both the Harris and Ullman Multiple Nuclei model and Forster model shown above highlight the interdependence of central business districts and suburbs in a multi-nuclei metropolitan area. This is supported by Bogart’s assertion (2006: 4) that the modern USA metropolitan area, ‘is not a set of islands—downtown, neighborhood, edge city, empowerment zone—that can be neatly separated and analyzed’. He argues that urban living ‘is a complex web of relationships’ that necessitated multiple cross-town journeys for day-to-day activities and encouraged people to abandon inner city living and mass transport for decentralised living with the convenience of personal transport. These conditions are addressed in an overview of the theoretical framework of urban morphology, which describes the complex web of relationships characterising urban form.

2.1.2 Urban morphology and urban design

In reviewing issues and challenges in urban morphology, Jeremy Whitehand (2012: 55) asserts ‘its most literal and widely accepted definition is the study of urban form’ or structure (without defining what is urban form). Urban morphology has several schools of thought from Kohl (1841—German school), Muratori (1959) and his disciple Cannigia (1979—the Italian school), Conzen (1960—the English school), to Kropf (1993—integrating Italian and English approaches), Leon Krier (1998) and Duany (2000—new urbanism), as cited in Osmond (2010: 7) and Scheer (2010: 21). The common elements in this field include a classification of building form types and use types; plots (lots) and blocks; street hierarchies (nodes and channels); and larger scale urban units of urban fabric (tissue, texture). Hence these urban morphology categorisations clearly include physical elements relevant to this thesis.

An extensive search of more than 40 books and numerous peer reviewed journal articles on city planning and urban design failed to find a uniformly accepted definition of *urban form*. Much discussion describes or refers in passing to urban form without actually defining it. Even books that include it in the title such as Cuthbert (2006) and Scheer (2010) define urban design at length, but provide no definition of urban form. Kevin Lynch’s view in *Good City Form* (1984: 48, 345) is that:

> Settlement form is the spatial arrangement of persons doing things, the resulting spatial flows of persons, goods, and information, and the physical features which modify space in some way significant to those actions, including enclosures, surfaces, channels, ambiences, and objects. Further the description must include the cyclical and secular changes in those spatial distributions, the control of space, and the perception of it.

Lynch continues to acknowledge the 'breadth and complexity' of the definition and that this is an incomplete description, because it excludes the full 'social, biological and physical whole'; and the role of time, or temporal organisation (1984: 451-453), in the story of a city. This definition is categorised by Lynch (1984: 37) as a normative theory (although it clearly has elements of a functional description), which deal with the 'generalizable connections between human values and settlement form, or how to know a good city when you see one'. However, it is considered to be rather too abstract for the purpose of this research. It tends only to allude to the three dimensional character, density and shape of the built environment that results from the metabolic flows of goods and energy as a product of design and development. Lynch (1984: 47) also refers to a more traditional description of settlement form as 'the spatial pattern of the large, inert, permanent physical objects in a city: buildings, streets, utilities, hills, rivers, perhaps the trees. To these objects are added a miscellany of modifying terms, referring to their typical use, or their quality, or who owns them'. This view aligns more with current urban morphology theory.

The research has taken into account multiple urban planning and design sources and the Chapter 6 analysis to offer a comprehensive definition of urban form as a first contribution of this thesis. In the Australian and general planning context it describes the physical entity of an urban area. This definition is presented in the bold text below.

> **Urban form is a set of complex relationships comprising: the development patterns and spatial structure in a hierarchy of scales (the urban fabric); the height, shape, density and appearance of the built environment; the interface between the built environment and public realm (streets and public spaces); movement hierarchies, networks and transport systems; public and private open space; as developed within the historical, geographical, ecological and climatic context. This definition could be extended to depict urban form as arising from—and supporting, facilitating and sustaining—the socio-economic functionality of a city, including social and cultural processes, metabolic flows of substances, goods, energy and communication.**

In relation to the second notion defined above, Karl Kropf (2011: 394) asserts that urban form should be understood as 'the result of a process ... fundamentally a social and cultural process'. His hierarchy of form scales is based on street, plot and building patterns, combined as 'urban tissue'. Stephen Marshall (2005: 248) suggests 'using the street as the basic building-block of urban structure' with 'patterns created from combinations of street type'.

In contrast to urban form, urban design has many definitions, e.g. as surveyed by Madanipour (1996: 93-117), Jenks et al. (1999) and Carmona et al. (2010: 3-15). A collective view of these notions identifies urban design of buildings and infrastructure as being at a scale greater than architecture, but less than whole settlements. It has been viewed as joining up the domains of architecture, city planning, landscape design and engineering (Gindroz et al. 2003: 17), and has been defined in terms of product and/or process orientation. The product-oriented tradition (Carmona et al. 2010: 6) focused on the visual qualities and aesthetic experience of urban spaces (e.g. Sitte 1889 reproduced in Collins and Collins 2006; Krier, R. 1979). In contrast, Carmona et al. (2010: 3) adopt a broad understanding of urban design as 'the process of making better places for people than would otherwise be produced'. This approach is supported by Frey (1999: 16) who summarises urban design as 'an activity that should be shared by and be the responsibility of all those involved in and accountable for urban development and regeneration'. Its task is to improve, by design of the city region, the city and its districts, 'the physical form and structure: the network of important public streets and squares, and individual spaces' (Frey 1999: 16).

More emphasis has now been on place-making activities for urban space as the public places that people can use and enjoy (Landry 2006; Girardet 2008; Gehl 2010). The 1996 Charter of New Urbanism (Gindroz et al. 2003: 18-22) introduces 'sustainable urbanism' and codifies 27 principles that 'represent the philosophical essence of urban design', including 'the reconfiguration of sprawling suburbs into communities of real neighborhoods and diverse districts' and 'restoration of urban centers'. The Charter seeks to reduce dependence on the car and to conserve energy. These principles have been built upon in more recent studies (e.g. Barton 2000; Riddell 2004; Register 2006) and are considered to be relevant to transforming cities to an oil-constrained future.

Marshall and Çalişkan (2011: 413) also distinguish between urban morphology and urban design as products and processes respectively, within a framework based on 'the physical fabric and the abstract domain, in relation to time order'. Morphology tends to look backward (a) and design tends to look forward (c) in time (**Figure 2.3**).

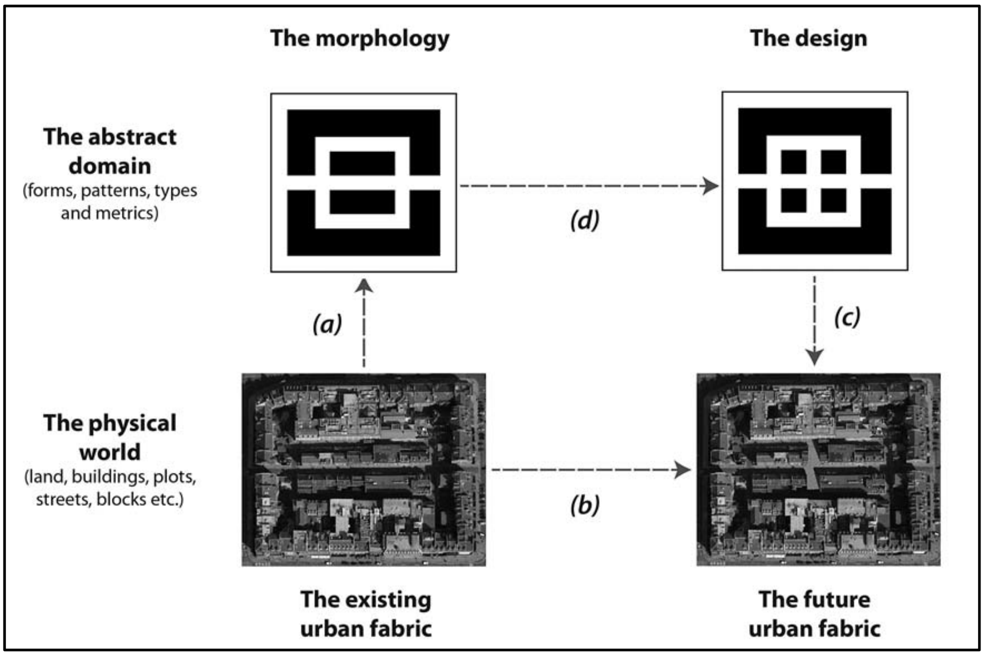


Figure 2.3: Joint framework integrating urban morphology and design

Source: Marshall and Çalişkan (2011: 415)

While the thesis research is morphological in describing the urban sprawl resulting from the oil economy, it is essentially linked by the change process in oil depletion to adapt future urban design, in terms of building types, density and structure. Marshall and Çalişkan (2011: 419) point out that an urban design outcome 'could be poor or dysfunctional if it copies from urban exemplars with poorly performing morphology'. This is likely to be the case if planners and architects use twentieth-century maladaptive design and technology in an oil-constrained future. Hence the impact of oil constraints on construction and the urban fabric primarily affect urban design at the lot, precinct and neighbourhood scales, which may be reflected in the changing form of urban morphology and morphogenetics (Whitehand 1981).

Paul Osmond (2010) proposes a classification of urban form based on an urban structural unit (USU) framework, building on earlier systems of classification devised by Kropf (1993) and Böhm (1998). Osmond (2010: 18), citing Kropf, points out that 'land use describes a particular relationship between humans and urban form … however, it does not describe urban form'. The USU is relevant (see glossary image), because similar to Osmond's view, the thesis analyses materials and energy flows that contribute to and assist in characterising urban form through the urban metabolic processes. The land use pattern and particularly the urban residential typologies are of course reflected in the urban form, while the metabolic processes are mostly hidden.

This section has established the general context of urban form and related it to morphology and urban design concepts. The choice of an Australian reference city for this research will determine the particular urban form characteristics as a basis for morphological description and the urban residential case studies. The reference case study city selection and justification is thus appropriately described in the next section.

2.2 Reference city selection

Selection of an Australian reference case study city is focused on a 'representative' city where continuing growth management is expected to be more affected by possible future oil constraints. Such a case study city is preferably one that is not deeply tied to, and constrained by, the historical roots of Australian settlement; yet is internationally recognisable for the benefit of a wide readership of this thesis. It should also be a manageable size for this PhD research. These overarching criteria tend to discount choosing a capital city, but suggest a mid-size city that has relevance to cities in other western countries. This aim accords with making the thesis research relevant on a global scale and thus increasing its value as a contribution to knowledge. This section develops a rationale for and justification of the reference case study city.

2.2.1 Australian coastal cities

Any superficial view of the Australian continental map easily reveals the overwhelming predominance of the coastal urbanised development. All the state capital cities are coastal metropolises with development sprawling into and absorbing towns in the surrounding hinterland regions. In a sociological study of Australian society, Bernard Salt (2007: 128) argues that 15 million Australians fall within the 'orbital influence' of capital cities so that approximately 75% of the nation is tied to the 'big city'. However, of that number 11 million live in suburbs more than five kilometres from the CBD within these entities, so that 'the largest cultural grouping' is the suburbanites. This view is reinforced by the survey of suburban history and urban sustainability quoted in section 2.1.1 by Davison (2006: 202-205). This cultural dominance is also evident in the relatively few mid-size regional cities over 100,000 population, such as Newcastle and Wollongong near Sydney, Geelong near Melbourne, Gold Coast and Sunshine Coast near Brisbane. The major coastal cities are magnets for population growth and prosperity as the drivers of the Australian urban economy. Of the mid-size coastal cities, the City of Gold Coast stands out as a suitable candidate for a reference city. The characteristics of the Gold Coast are described in the next section.

2.2.2 City of Gold Coast

The City of Gold Coast is a coastal lifestyle-tourist city of 550,000 residents in the South East Queensland (SEQ) region of Australia. The city is actually an amalgamation of a narrow linear coastal city with a much larger hinterland formerly called Albert Shire, which prior to 1994 provided the expansion area for suburban growth and competed for population and urban facilities. The city meets the selection criteria as the case study area for this research, as a mid-size city with high growth rate issues:

- The Gold Coast was only proclaimed a city in 1959 (Prideaux 2004). It is largely a product of the twentieth century.
- It is Australia's sixth largest city and one of Australia's fastest growing cities over several decades at about 7 per cent annually and an average of 4 per cent between 2001 and 2008 prior to the global financial crisis (GCCC 2010b). The local government is the second largest declared city area in Australia (after Brisbane), at 1333 square kilometres.
- It is situated in the mid-eastern coast of Australia spilling over the border between Queensland and New South Wales. The city has developed as an urban conglomeration of a series of historic seaside holiday villages, conjoined into a linear multi-nuclei tourist resort and lifestyle city, with semi-rural exurbs, sugar cane land in the northeast, and an elevated hinterland of national parks (Mullins 1990: 37; Prideaux 2004: 33). It encapsulates many features of other large coastal cities in Australia, which are the predominant settlement pattern, except for several regional activity centres supplanting a dominant Central Business District.
- It is an internationally recognised tourism city, aiming to be a world-class city and the venue for the 2018 Commonwealth Games, making it suitable for this study.

The Gold Coast context map in **Figure 2.4** shows a poly-centric settlement pattern with the high density Southport-Broadbeach strip (see inset) set to be redeveloped as a high density residential spine along the light rail (tram) line which became operational in 2014. The Coomera-Pimpama area in the top of the map is the last major greenfield area and is promoted as a 'transit supportive neighbourhood', (GCCC 2010a) focused on the proposed town centre at Coomera rail station.

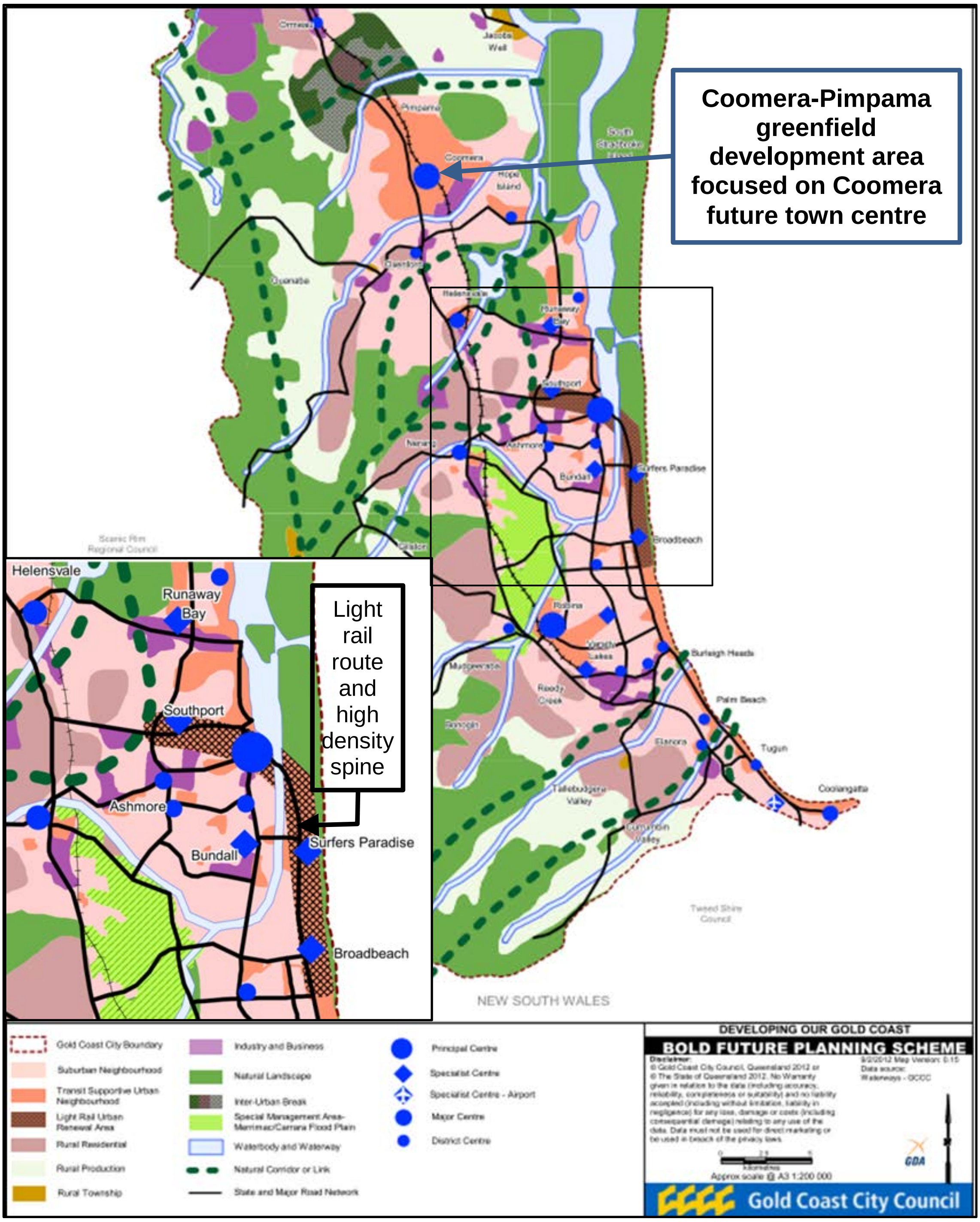


Figure 2.4: City of Gold Coast draft strategic plan context map

Source: Draft *Bold Future* planning scheme (Gold Coast City Council 2012)

Since the 1970s, the city has been a dynamic exemplar of innovative residential development, ranging from high rise tower buildings and canal estates along the coast, inner urban activity centres spreading out from traditional and new town centres, to the sprawling hinterland suburbs and semi-rural exurbs. Other relevant characteristics that make it a suitable reference city include:

- The 2011 census population was almost 550,000 (QTT 2013). The Gold Coast's long and sustained growth is likely to continue into the future with a future population of over 798,400 projected by 2031 (medium series - QTT 2013).
- The city urban footprint has a limited supply of urban broadhectare land, which provides a timely opportunity to re-think strategies in the context of future population growth of 284,400 by 2031 (55 per cent in 20 years)
- There are no temperature extremes which would distort the standard of building construction. The climate is coastal sub-tropical with hot wet summers and relatively mild winters. Building insulation is necessary mainly for hot conditions.
- Building styles have been sourced from around the world, as developers compete for the owner occupier, tourism and investment markets. It therefore has a variety of building types from which to draw case studies to investigate the research questions.
- It has a sophisticated planning scheme (Gold Coast City Council 2010a, 2013e) and has been preparing a Peak Oil Management Plan since 2010.
- The city is part of SEQ, subject to a 2009 Regional Plan for growth management.

The conclusion is that the City of Gold Coast meets all the selection criteria as the case study area for this research, being a mid-size city developed from the mid-1900s in the cheap oil era, which has high growth rate issues and is consequently worth studying.

2.2.3 Urban residential typologies

Australian residential development has a diversity of settings in the urban form, largely based on historical precedent as described in section 2.1.1; particularly in a suburban, as opposed to a compact urban setting, such as the City of Gold Coast. The study of a city can be assisted by depicting a geographical transect, as a sequence of building typologies varying in scale and density from a central business district (CBD) through the inner urban and low density outer suburban areas to the rural hinterland. This is most evident in a mono-centric historical city or a small town, and less so in a multi-nuclei car dominated city. A study of South East Queensland (SEQ) cities for the Council of Mayors (SEQ) and Queensland Government (Council of Mayors SEQ 2011) attempts to discover a hypothetical SEQ Place Model transect. The model draws heavily on American new urbanism theory and a similar transect in *The Smart Growth Manual* (Duany et al. 2010). **Figure 2.5** shows part of the urban transect, omitting the very low density outer suburbs and hinterland village areas. The SEQ study acknowledges that the Place Model is an illustrative concept that 'can help organise different parts … and inform the distribution, balance and role of each place' (Council of Mayors SEQ 2011: 9).

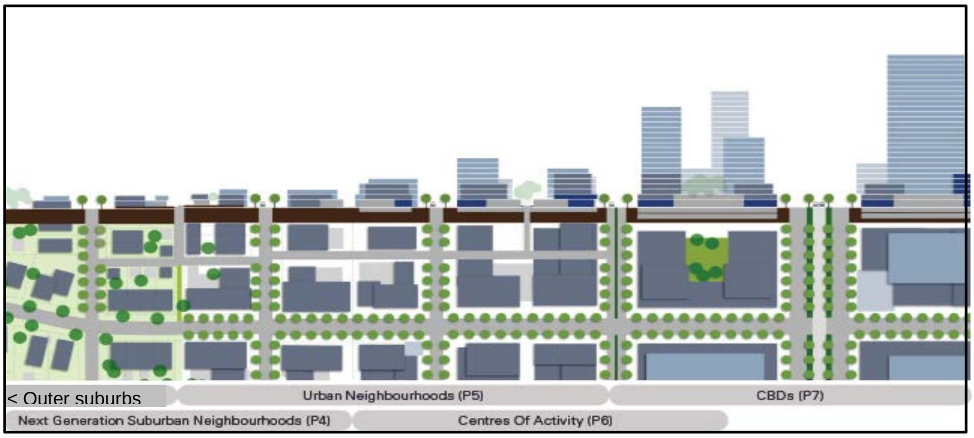


Figure 2.5: Conceptualised urban transect of a South East Queensland city

Source: Council of Mayors (SEQ) (2011: 10)

The SEQ study is published as the *Next Generation Planning* handbook as a guide for urban planners, designers and developers to adopt detailed codified new urbanism planning principles at all urban scales. The handbook also acknowledges that 'real cities and regions are a complex arrangement of centres, nodes, corridors, districts and features unlikely to appear in such order' (Council of Mayors SEQ 2011: 115). The conceptual transect is therefore not evident in a consistent way in the City of Gold Coast, as indicated in Figure 2.4, because the haphazard historical development pattern has resulted in a coalescence of coastal and hinterland villages. However, it is useful as a morphological model to describe a more specific gradation of development intensity than that depicted in the historic models of urban form shown in Figure 2.1. It assists in identifying a range of urban residential typologies representing the central, inner urban and outer suburban areas noted in the handbook and evident in the city.

The conceptual transect in Figure 2.5 illustrates the built environment as having the greatest height and density (and land values) in the CBD, a zone containing both commercial and residential towers. The urban neighbourhoods show a graduation from dense medium rise apartment towers, to three storey type apartments, to low density one–two storeys attached and detached dwellings in so-called Next Generation Suburban Neighbourhoods. The street patterns in Figure 2.4 are a consistent stylised hierarchy of residential access streets and arterial traffic roads of varying width according to their function. Again, this is an idealised concept, realised in historic traditional grid cities and new urbanism planned development. The urban transect model is nevertheless a useful tool to conceptualise residential typologies for oil depletion adaption strategies.

While the existing and planned urban form provides the morphological setting, the buildings themselves are the products of technological design and construction processes, with varying quantities of renewable and non-renewable materials, each having different embodied energy. Every residential building type has a characteristic identity, which is generally related to the manner of attachment (whether side-by-side or stacked); height in storeys/levels and floor area (Australian Government 2008).

Michael Ambrose, contributing to an Australian study of sustainable pathways edited by Peter Newton (2008: 425-427), reaffirms that 'energy efficient design is not a new idea ... Many of the principles are taken from traditional building practices that date back centuries.' Thus, the principles of insulation, ventilation, solar orientation, shading of walls and windows, and beneficial landscaping are well known to the architectural and urban design professions, influencing urban forms at the local scale.

However, these principles can be adversely affected by poor subdivision design practices to lessen the advantages of environmental and climate sensitive design. Hence, the subdivision practices and building design in a suburban setting influence the housing operational energy usage, particularly in respect of space heating and cooling—most of which comes from fossil fuel sources (Newton 2008: 429). Traditional housing and subdivision design is well expounded by many authors, including Alexander et al. (1977), Riddell (2004) and Roaf et al. (2007). Such designs will be important in an oil constrained future when more viable alternatives to contemporary housing planning, design and building practices will be required. Energy efficient design applies equally to inner city medium and high density residential building typology and is the subject of green or smart building rating schemes, including both embodied and operational energy usage (e.g. Green Building Council of Australia 2009).

2.2.4 Case study building typologies

A key part of this thesis is to discover if some types of contemporary residential land development and building typologies are more vulnerable to oil depletion than others. If this is the case, it may affect the sustainability of new residential development in the medium to long term, and hence the urban form. This is identified as the ultimate dependent condition for study in Figure 1.3 and further addressed in Chapters 3, 5 and 6. The current urban residential typology relevant to Australian circumstances and particularly to the reference case study City of Gold Coast is broadly identified below:

A. Detached and semi-detached houses of 1-2 storeys (the predominant suburban style)

B. Attached town (row or terraced) houses, and apartments (2-3 storeys) above parking; typically with individual heating ventilation and air-conditioning (HVAC) systems

C. Medium rise, medium density apartments (4-8 storeys) with lifts (elevators) and typically with integrated HVAC systems

D. High rise apartment towers above 8 storeys with lifts and integrated HVAC systems.

The representative residential typology is illustrated in Figure 2.6. Commonly used construction elements of the representative housing types are compared in Table 2.1. Two of the drivers identified in this thesis are the emerging energy crisis in oil supply and the urgency to mitigate greenhouse gas emissions contributing to climate change at all scales of the urban form and building typology. This research focuses on the energy crisis, while advocating energy transition for climate change see section 3.2).

Figure 2.6: Representative Gold Coast residential building typology

Source: Photos by the author

Table 2.1: Construction Elements of Representative Housing Types

BUILDING TYPE	MAIN STRUCTURAL MATERIALS:			WINDOWS DOORS	HVAC*	COMMON ELEMENTS
	FLOORS	EXT. WALLS	ROOFING			
A Detached house	Mainly concrete slab on ground; raised timber ground or upper floors.	Cavity brick or concrete block structure or cladding. Timber or steel frame with brick veneer. Lightweight sheet or foam board. Paint or rendered finish.	Timber or steel truss/framing With clay or concrete tiles, metal tiles or sheeting; Less common: fibre cement sheeting or slate (rare).	Windows: aluminium, steel, timber or plastic frame with float glass. Some double glazing. Doors: timber, steel with timber or steel frames.	Normally natural ventilation; Ceiling fans; Individual unit air conditioning units or systems	Plumbing: ** PVC plastic, copper piping; steel or plastic gutters and downpipes. Electrical: PVC coated cabling, steel and plastic installation fittings. Insulation: fibreglass, wool, paper, rockwool, aluminium foil.
B Three storey apartment building	Concrete slab, suspended slab; raised timber upper floors.	Cavity brick or concrete block structure. Timber or steel frame with brick veneer. Lightweight sheet or foam board. Paint or texture rendered finish.	Timber truss or steel frames with clay or concrete tiles, metal sheeting. Some flat metal roofs. Some green or walkable roofs.	Windows: aluminium, steel, timber or plastic frame with glass. Some double glazing. Doors: timber, steel with timber or steel frames.	Combination of natural ventilation, fans, air conditioning units or systems for individual dwellings.	
C Six storey apartment building	Steel reinforced concrete slab, suspended slab system flooring.	Rendered cavity brick or concrete block loadbearing or infill panels. Rendered steel reinforced formed concrete. Some glass curtain walls. Balcony metal or glass panel balustrades.	Steel frames and pitched or flat sheet roof in metal; or concrete slab. Lift and air conditioning plant rooms in metal, block, lightweight cladding with embellishment. More green or walkable roofs.	Windows: steel, aluminium or plastic frame with glass, window walls. More integrated window walls. More double glazing. Doors: timber, steel.	Combination of natural & mechanical ventilation, with fully integrated HVAC, or air conditioning to individual units.	AS ABOVE with higher standard of materials for safety and durability. Fire detection systems with galvanised steel and copper piping.

D 30 storey apartment tower	Steel reinforced concrete slab, suspended slab system flooring.	Rendered steel reinforced formed concrete. Infill cavity brick or concrete block. Integrated glass curtain walls. Balcony metal or glass panel balustrades.	Flat sheet roof in metal, or concrete slab. Lift and air conditioning plant rooms in metal, block, lightweight cladding with embellishment. Some green or walkable roofs for penthouses.	Extensive use of integrated window walls with double glazed or toughened glass. Doors: timber, steel.	Primary: Mechanical ventilation with fully integrated HVAC systems. Secondary: Natural ventilation via balcony doors and windows.	AS ABOVE with higher standard of materials for safety and durability. Fire-fighting systems in building with more than 10 storeys with galvanised steel and copper piping.

* HVAC = Heating, ventilation, and air conditioning systems

** Internal plumbing fixtures and fittings in plastic, ceramic and vitreous enamel materials. Increasing transition from ceramics and vitreous enamel to acrylic plastics

The table indicates an increasing complexity in each broad building type from category A to D that is reflected in the sophistication of construction processes. This may also imply greater embodied energy in the structural materials for buildings of similar economic life spans. Appendix A section 2.3 and Chapters 3 and 4 address how the building elements may be assessed in relation to oil-related inputs.

Section 2.2 has related the general urban form context established in section 2.1 to the Australian circumstances by applying it to the selection of a reference case study city: the City of Gold Coast in South East Queensland. Urban residential typologies are related to the SEQ context through a study that presents a Place Model as an illustrative urban transect. While it is acknowledged to be hypothetical, it assists in identifying a range of building typologies representing the central, inner urban and outer suburban areas evident in some parts of the reference city. This is the basis for proposing four case study residential buildings relevant to Australian circumstances and representative of the reference case study City. The next section explores how the urban form may be influenced by, and responds to, the concepts of sustainable development.

2.3 Urban form and sustainable development

This thesis investigates how the future prospects of petroleum supply constraints may gradually affect residential (and other) building types and influence an urban design transformation towards the conditions of an oil-constrained city. This transformation necessarily involves a planning response to the range of concepts and constructs broadly called sustainable development theory, on which this thesis is grounded. This section is an overview of relevant aspects in the evolution of this body of theory.

In a wide-ranging study of evolving American urban design, Brenda Scheer in *The Evolution of Urban Form* (2010) poses questions about why urban design and hence urban form respond with mixed results to changing cultural, technological and economic conditions. She offers explanations for why the static view of American cities set out in land use and zoning plans is at odds with the dynamic nature of these rapidly evolving conditions, and how the managers of urban development must understand and strategise the drivers of economic and cultural transformation and obsolescence. These similarities of American and Australian urban sprawl make Scheer's observations relevant to this research.

Scheer's approach to urban form evolution could be applied to peak oil impacts as a response to new conditions, favouring a change to an alternative set of residential building types. Scheer (2010: 1-3) contends that in the USA zoning has had 'a very limited effect on urban form', except for the underlying cadastre of streets and plots. In her view, urban design is more a function of street layouts, parcel size and shape, building form, public spaces and scale. Building height and bulk, as well as style and appearance, contribute to such building form. She suggests that 'managing the dynamic of typological change is an essential skill for planners'. Appropriate planning responses to future oil constraints would therefore be key elements in managing urban design, in what Scheer describes as 'a framework for change that is continuous and ever evolving'. Notwithstanding her view, Bertaud and Malpezzi (2003) argue that 'urban structures are very resilient and not easily altered'. This is evident in the persistence of low density suburban development forms in Australian cities, the USA and elsewhere.

Scheer (2010: 3) cautions that 'it is not possible to invent new types or substantially alter a type solely for the purpose of serving a different kind of urban design idea'. However, she acknowledges that dramatic changes have taken place in the USA in the last century, *inter alia*, by globalisation of the economy and technological shifts in construction and transportation. This thesis is premised upon the notion that the twentieth-century oil economy is shifting irreversibly in this century toward a different paradigm of transport and static renewable energy sources, and possibly to radically different economic and technological conditions. The underlying conditions could possibly lead to the collapse of societies that continue to rely on fossil fuels and use these and other resources unsustainably (Diamond 2005; Heinberg 2007; Slaughter 2010; Gilding 2011). Such considerations provide the imperative for planners and designers of urban form to be strongly influenced by the concepts of sustainability.

2.3.1 Urban form and concepts of sustainable development

The spread of suburban and outer city living and transformation away from the traditional compact city form introduced in section 2.1 has led planning policy and practice to adopt evolving sustainable development theories relating to future urban growth management, mainly through urban consolidation. Since World War II, the town planning and related professions have sought to control and manage the growth of cities, limit peri-urban sprawl and address the problems of informal (squatter) settlements in many urban centres of both the developed and developing world (Droege 2006: 22). Local governments in Australian cities have developed planning schemes and more recently growth management strategies. Such strategies have introduced systematic land use regulations; however, suburban sprawl has continued in the spread of city footprints, even with urban boundary controls in some cities.

The 1991 Council of Australian Governments' commitment to reduce urban sprawl and promote urban consolidation led to the Building Better Cities programs and the Green Street initiative, which was last published as *AMCORD: A National Resource Document for Residential Development* (Australian Government 1995). While AMCORD was adopted by many local governments, it was superseded by later codes. Although commitments at state and local government levels to reduce urban sprawl have been in effect for over three decades, Newman et al. (2009: 4) note that cities globally 'now consume 75% of the world's energy and emit 80% of the world's green-house gases'. They concede it is not all related to oil-based energy; yet transport alone accounts for between one-quarter and one-third of all energy consumption. Promotion of urban consolidation by policy-makers since the 1980s is also linked to the concept of ecologically sustainable development. The Brundtland Report (1987: 8) definition is:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The Australian Government definition of ecologically sustainable development that was adopted by all states in 1992 has a more targeted focus on resources linked to improving an ambiguous 'future'. This definition includes petroleum in all its forms as a non-renewable resource that has increased our quality of life, even if in unsustainable ways. The 'ecological processes' could be extended to urban metabolism:

> Using, conserving and enhancing the community's *resources* so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased. (Australian Government 1992) [Emphasis added]

The study of sustainable cities from a planning perspective has tended to focus on 'new urbanism' mixed use development (Van der Ryn & Calthorpe 1986; Calthorpe 1993; Duany et al. 2000; Kolb 2008; Coyle 2011); the compact city form with 'smart growth' (e.g. Jenks & Dempsey 2005; Andrews 2007); and 'transit oriented development' (Dittmar & Ohland 2004; Dunphy 2004). Bossel (1998) introduced a systems model approach to sustainability thinking, that has a strong ecological emphasis. Sustainable urban planning is now expressed in terms such as 'eco-cities', 'eco-villages' or 'eco-neighbourhoods', as defined in the glossary (Barton 2000; Neal 2003; Riddell 2004; Register 2006; Girardet 2008; Newman & Jennings 2008).

However, there has also been a counter culture to compact city form, as typified by support for suburbs from Troy (1996) and Stretton (1996) and studies such as *Superbia* (Chiras & Wann 2003), *Don't call it sprawl* (Bogart 2006) and *Retrofitting Suburbia* (Dunham-Jones & Williamson 2009). These works tend to celebrate suburbs and understandably attempt to improve existing suburban lifestyle by nodal transit oriented development and creation of social spaces. Lewis (1999) and some groups such as the Melbourne based Save Our Suburbs (Cox and Pavletich 2010) go further in defence of suburbs to suggest that urban policies increasing residential density have the effect of reduced housing affordability so that 'the traditional way of life is thus being slowly crushed under the bureaucratic iron heel of high-density' (Cox & Pavletich

2010: ii). Davison (2006: 209) considers urban consolidation policies fuelled a rhetoric of blaming 'suburban sprawl' for the 'many perceived environmental and social failings of suburbs', overlooking the positive and practical values of suburbs 'as places of emotional, moral and spiritual refuge'. While city renewal results in the gentrification of inner and middle suburbs, it also sees pressures on public infrastructure and a haphazard market-driven redevelopment pattern with serious traffic congestion in the *auto city* (Newman & Kenworthy 1999: 31). Despite the calls for more compact urban development, Forster (2004: 173) considers there is still no clear consensus about the most sustainable and efficient structure for Australian cities, given the predominance of low density suburban housing.

Giddings et al. contributing in Jenks and Dempsey (2005: 24), expand the socio-economic dimension of 'total quality of life' in the definition of ecologically sustainable development. They suggest that 'a foundation to urban sustainability is the overriding objective to achieve a high quality of life for the whole community within a socio-economic framework that minimizes the impact of the city on the local and global environment' (2005: 24). This notion builds on research by Ted Trainer (1996), who argues that the limits to development growth include availability of resources such as minerals and oil and advocates transformation to a radical conserver society. Paul Gilding (2011) further extends this theme to the imperative of achieving a global steady state economy. However, Davison (2006: 202) asserts that in the then current debates about urban sustainability focusing on the benefits and costs of urban consolidation, 'there has been remarkably little discussion about the idea of suburban sustainability, although there are recent signs that this may be changing'. He supports the view that 'the goal of sustainable development brings with it profound implications for all Australian resource use and settlement patterns' (Davison 2006: 202, citing Yencken & Wilkinson 2000). These underlying principles are revisited in section 2.2.1.

The resource aspect of sustainability is considered to be important for this study, because cities in developed countries depend so heavily on the oil economy (e.g. Droege 2006). Vulnerability caused by future oil depletion could fracture the socio-economic framework and drastically affect the quality of life, particularly at the vulnerable suburban scale (Newman et al. 2009). Yet Davison does not factor in such potential impacts of future oil depletion in his support of suburban sustainability. The concept of sustainability presented by Riddell (2004), Bruegmann (2005), Register (2006) and Newton (2008) introduces an important aspect of the value of adaptation to future oil depletion and other non-renewable resources, for immediate as well as longer term inter-generational benefits. Riddell introduces the term 'sustainable co-dependency' to foster greater community involvement, equity and accountability in decision-making (2004: 100). This discourse raises issues of whether such adaptation is an end in itself, or just one important means to achieve the wider ends of sustainable development, including well-being, livelihood and inter-generational equity, as well as climate change mitigation and adaptation benefits. These issues are elaborated below.

2.3.2 Sustainability and urban regeneration

This section elaborates on the theoretical concepts and terminology of sustainability, resilience, regeneration and transformation as the foundations for the cities of the future. The concepts and theories about sustainability have been widely debated and used in planning and environmental literature (Wheeler 2004: 20-23). Many definitions of sustainability have been offered to extend and overcome criticisms of the Brundtland definition (e.g. summarised in Wheeler 2004: 24). Some definitions avoid the problems and debates involving questions of 'needs' or 'carrying capacity' measurement and nominal end 'steady states'. Wheeler himself (2004: 24) defines sustainable development as 'development that improves the long-term health of human and ecological systems'. He argues that there is a debate between focusing on economic values, social needs and intergenerational equity, or ecological stability, which somewhat reflects 'differences between the modernist, postmodernist and ecological viewpoints' (Wheeler 2004: 30). Such widely differing ontological world-views, as well as assumptions about reality, influence the values that people adopt and the priorities which motivate behaviour, including the urban planning paradigms at the heart of this thesis. Wheeler (2004: 31) suggests that 'sustainability itself is a code word for other values—principally the sustaining and nurturing of life on the planet—that becomes a starting point for action in urban planning'.

A report on the multi-disciplinary sustainable development literature by Jabareen (2009: 55) reveals 'a lack of a comprehensive theoretical framework for understanding the phenomenon and its complexities'. He points out that is no clear consensus on 'what it is that needs to be sustained.' More recently Sala et al. (2012), writing about progress on the emerging discipline of Sustainability Science (SS), do address this question in relation to development of a conceptual framework for the science. They suggest that SS is characterised by a trans-disciplinary focus on 'dynamic interactions between nature and society' relating to vulnerability and resilience of 'complex social-ecological systems'; pursuing a normative function 'to provide direction through visions and goals … of how human-environment systems would function and look in compliance with a variety of value-laden goals and objectives' (Sala et al. 2012: 5). Their conceptualisation of a model for SS framework addresses the questions 'What is to be sustained?' and 'What is to be developed?' and 'over what scales in space and time are those relationships meant to hold?' yields the diagram in **Figure 2.7**. It underscores the dilemma of differing values, goals and levels of geographic and temporal scale (2012: 6-7). The relationships are informed by an ecological approach resting on a broad range of principles that represent the ontological part of the framework. In relation to this thesis the principles could also include land use planning concepts and systems as part of 'good governance'. Oil would form part of abiotic resources; and the research focus is at the local city spatial scale and 'now and in the future' temporal scale.

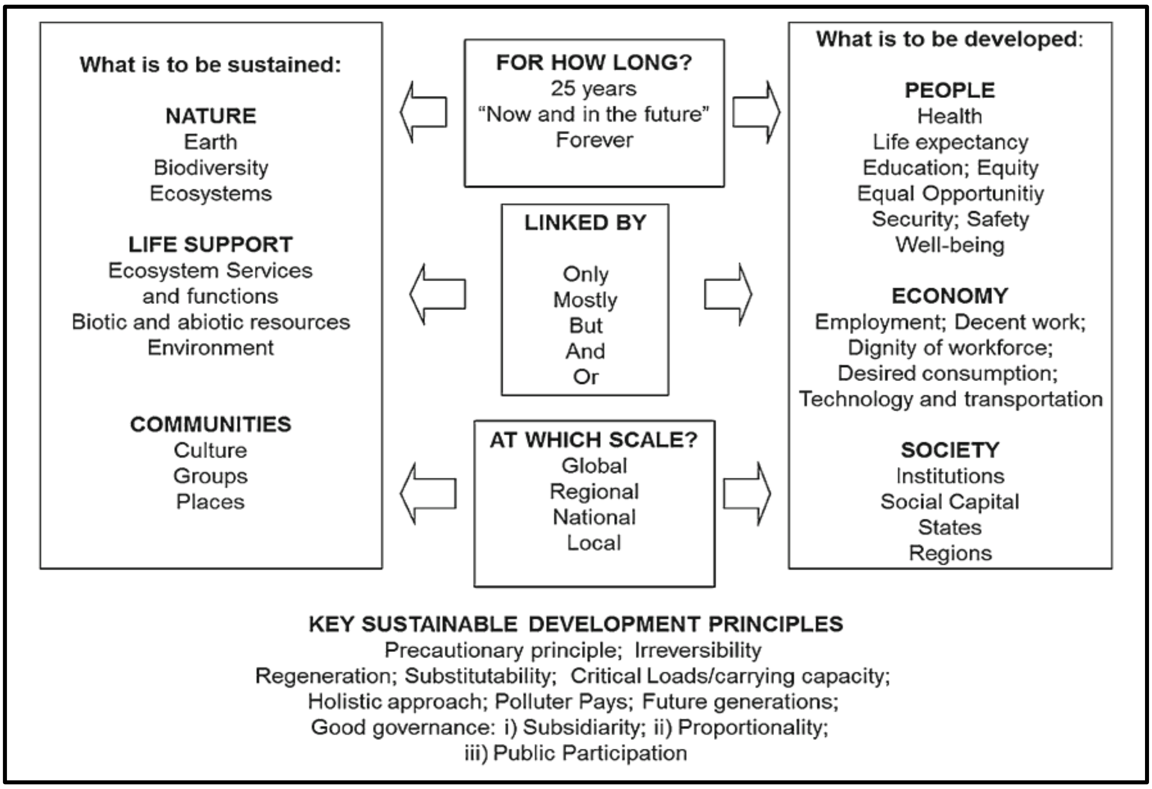


Figure 2.7: Classification of the many framings for sustainable development

Source: Sala et al. (2012: 7)

The ecological values and principles in Figure 2.6 are reflected in positions adopted by other writers. Newman and Kenworthy (1999: 17) adopt a somewhat postmodernist view, suggesting that 'the human quest, the process of civilization, the development of human society, is all about the growth of cities' and that 'the driving force behind the growth of cities is human opportunity'. However, they temper this notion with the caveat that the great challenge of our cities is the need to 'take seriously the quest for sustainability … by simultaneously using fewer natural resources, creating less waste, and thus impacting less on the natural world'. This theme is echoed by others, including Ken Yeang (1995: 3, 11) who asserts from an architectural perspective, that 'design and planning decisions that are made … not only have an immediate effect on human society, but also could influence the environmental quality for subsequent generations'. Yeang concludes that as the earth's resources are finite, 'the designer needs to optimise and conserve' them to ensure 'continued availability to future generations' (1995: 11). The World Future Council (WFC) cofounded by Herbert Girardet—quoted at the head of Chapter 3—asserts that since Rio 1992 conference, the notion of sustainable development 'has become utterly vague and is open to a wide spectrum of interpretations' (Girardet et al. 2013: 7-9). The WFC urges going beyond 'sustainability' as such to the concept of *regenerative cities*—from 'Petropolis' to 'Ecopolis'—which mimic the restorative relationships of 'circular metabolic systems found in nature'. The importance of these ecological values in relation to oil supply and depletion is highlighted by Diamond (2005: 509) in his warnings noted in the introduction to section 2.3 about the potential collapse of civilisations in that:

> A society's steep decline may begin only a decade or two after the society reaches its peak numbers, wealth and power … The reason is simple: maximum population, wealth, resource consumption, and waste production mean maximum environmental impact, approaching the limit where impact outstrips resources.

The themes about city building and resource conservation (in this case petroleum) relate to the concept of an oil-related urban metabolism model derived in Figure 1.2. A European consulting collective *Except Integrated Sustainability* also considers the Brundtland Commission definition of sustainability as lacking precision or measurability, as it describes what sustainability should lead to or looks like, and not pinpointing what it actually is (Except 2012). *Except* has researched an alternative definition based on a dynamic metabolic system, matched to an evaluation methodology:

> Sustainability is a state of a complex, dynamic system. In this state a system can continue to flourish without leading to its internal collapse or requiring inputs from *outside its defined system boundaries*. Applied to our civilization, this state is consistent with an equitable and healthy society, as well as thriving ecosystems and a beautiful planet. (Except 2012 online) [Emphasis added]

Applying this definition to existing cities is problematic in the broad sense. The city resource boundary extends into the hinterland and well beyond it for imported goods, so the limit of the system is contestable. A flourishing city implies economic growth, which can also extend the import resource boundaries. The city is not a closed ecological system, since exports from economic activity counterbalance imports of resources to manufacture physical goods. An energy balance is a desirable attribute and this certainly applies to petroleum substitutes, however uncertain in the short to medium term. Stationary energy provision from renewable sources is clearly desirable and European countries such as Denmark, Germany and Spain are showing it can be achieved (e.g. Droege 2006: 172-3). Likewise water and wastewater balance is essential in a fully regenerative city and is more achievable in a suitable climate. Food security is theoretically achievable if technological alternatives for petroleum (oil and gas) inputs are vigorously pursued.

Diamond's warning about potential collapse should be heeded as it may be relevant to the situation in the peak oil plateau of maximum oil production unless hydraulic fracturing of oil shales (tight oil fracking) prolongs this plateau indefinitely. Alternatively, the energy balance is transformed as the WFC and other groups advocate, and renewable energy becomes 'the key ingredient in the regenerative development of human settlements' Girardet et al. 2013: 13). Otherwise, as the WFC asserts, 'the ravenous appetite for our fossil-fuel powered lifestyles for resources from the world's ecosystems has severe consequences for all life on earth, including human life' in our future generations (Girardet et al. 2013: 7). This impinges on the intergenerational equity limb of the Brundtland (and other) definitions of sustainability.

A technical economic analysis of the Brundtland definition by Marc Fleurbaey (2013) examines the link between sustainability and intergenerational welfare, emphasising that 'focusing only on the opportunities left to future generations is a rather extreme approach to social welfare. So, sustainability can at best be viewed as a minimal and arguably insufficient obligation for the present generation'. However, he maintains that 'an important feature of the Brundtland definition is indeed that sustainability is a matter of sufficiency rather than optimality' (2013: 1). Fleurbaey argues that the ability for future generations to achieve similar or increased outcomes in the use of resources is determined by their successful management in the present generation, but that ability need not necessarily be maximised (2013: 5). He suggests that 'although sustainability indicators are easy to conceive in theory (though not in practice), focusing on sustainability in intergenerational policy issues may be quite questionable' (2013: 6). This is partly because the present generation cannot know what the future holds and what a future generation may set as its priorities, thus tending 'to deprive future generations from possibilities for its own benefit' (2013: 11); or could manage resources suboptimally. Fleurbaey suggests that as a desirable policy, sustainability is conceived as the present generation 'leaving the possibility for future generations to enjoy at least the same opportunities' (2013: 19). He qualifies this by suggesting that:

> Insofar as intergenerational welfare evaluation is meant to guide decisions, it would not make the decisions of the present generation depend on a precise prediction of what future generations will do. It would consider that it is enough to provide them with the means to have a good level of welfare. If instead they decide to make a special sacrifice for their descendants, this should not influence our current evaluation of the future (Fleurbaey 2013: 23).

These considerations certainly apply within this discourse to oil consumption issues in our current generation, but this researcher concludes that oil (and gas) depletion within the expected timeframes makes such a desirable policy unachievable over each successive generation. We are in the unique position of viewing the future from the peak plateau of oil production, as indicated in Figure 3.3, so could be lured into the temptation that technology will enable it to continue indefinitely (the modernist optimistic world-view, and promoted by fracking of tight oil). Looking ahead 20 years to the mid-2030s, in which timeframe both conventional oil and natural gas production will be in decline (looking ahead to section 3.1.2), our civilisation has never been in such an energy related turning point since the denudation of European forests. It leads to questioning the previous and current concepts of sustainability in terms of both our generation's ability to continue the expansionary pathways of development and its obligation to maintain the opportunities for future generations.

Other commentators cited in this Chapter (e.g. Chiras & Wann 2003; Bogart 2006; Davison 2006; Droege 2006; Dunham-Jones & Williamson 2009) may view this as an alarmist position, pointing to the growth in renewable energy sources taking over from oil and gas as part of the new sixth wave of innovation. John Short in *The Urban Order*

(1996:71) and Carmona et al. (2010: 24) review how these so-called Kondratieff long cycles or waves of technological, economic and social innovation have influenced urban development and form. These innovation waves have caused paradigm shifts in world development as shown in **Figure 2.8**. The knowledge economy in the fifth wave is being overtaken since the 1990s by an energy transition to a more sustainable renewable-energy economy in the sixth wave. This is also considered to be the period of peak oil supply. Newman et al. (2009: 53) affirm that the sixth wave 'coincides with the end of cheap oil … This all means the city can become much more polycentric … The polycentric centres and the remaining suburban buildings all need to renewed with solar and other eco-technologies'. Indeed Immanuel Wallerstein (2000) alludes to this major transition when he warns that:

> the modern world-system is in structural crisis and has entered into a period of chaotic behaviour, which will cause a systemic bifurcation and a transition to a new structure whose nature is as yet undetermined and, in principle, impossible to predetermine, but one that is open to human intervention and creativity. (Wallerstein 2000: 251)

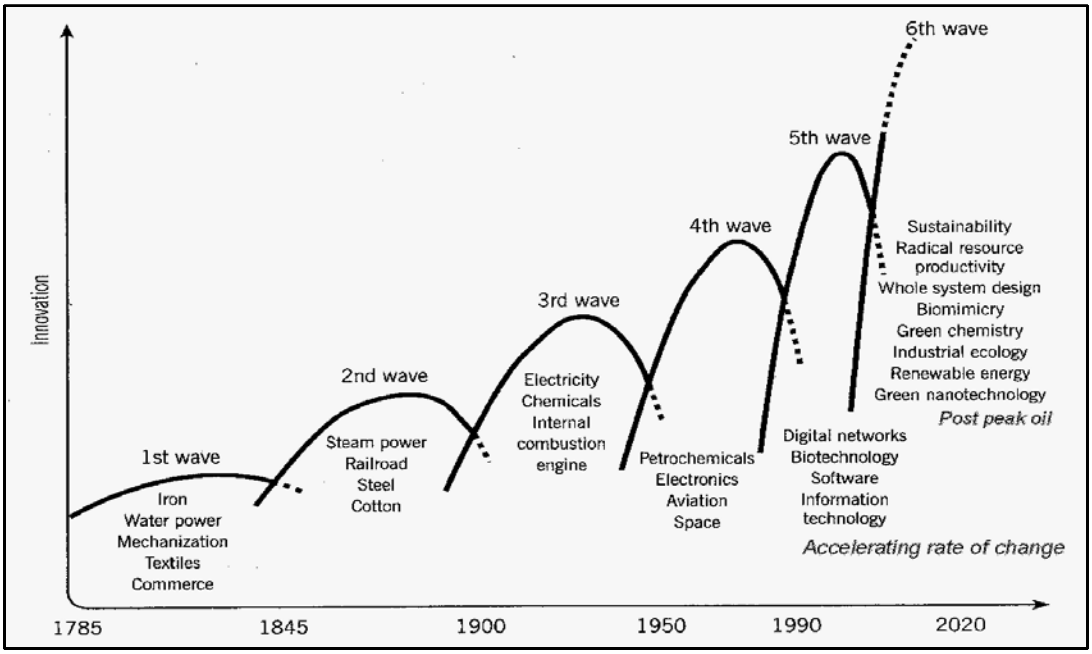


Figure 2.8: Kondratieff Cycles – Waves of innovation including peak oil

Source: After Hargroves and Smith (2005: 17)

The recent changes of federal and Queensland governments in Australia make this warning all the more relevant to the sustainability and resilience debate. The September 2013 federal elections resulted in a change from an Australian Labor Party government to a Liberal-National Party coalition. The new government immediately moved to implement election promises to rescind the carbon tax legislation in favour of a direct action climate change program and to terminate the Climate Commission, which the federal government relied upon for independent scientific and policy advice. The implications of new shifts in policy direction for sustainability in development were becoming evident at the completion of this PhD thesis with a change of federal government party leadership to bring climate change issues and the city back into focus (Liberal Party 2016). One could speculate that a shift towards growth oriented policies is more likely to return to a technocratic modernist viewpoint focussing on economic values as noted above. Such changes, without promotion of the renewable energy sector in Australia, could see an acceleration of resource consumption and an increase in greenhouse gas emissions, amongst other as yet unknown effects.

The need for 'human intervention and creativity' noted in the Wallerstein quote are important in the wider Australian economy, but also in the design and operation of our cities. In relation to the Gold Coast, the draft 'City Plan 2015' released in late 2013 for the state interest review (GCCC 2013e) is structured around six city shaping themes that represent the policy intent of the plan: creating liveable places; making modern centres; strengthening and diversifying the economy; improving transport outcomes; living with nature; and being a safe, well designed city. (GCCC 2013e: Part 3, Page 3). The aim is to make the Gold Coast more resilient in a changing economic environment.

This notion of resilience to a changing future leads into an exploration of the concept of *resilience* as applied to urban and disaster planning; and onwards to *transformation*.

2.3.3 Sustainability leads to resilience and transformation

Sustainability thinking has progressed to the concept of 'resilience' introduced in Section 2.3.2, and which has become a twenty-first century urban planning mantra. As with sustainability, many definitions of resilience also have been offered and debated (e.g. summarised in Manyena 2006: 437; Ward 2007; and Newman et al. 2009). Although the resilience concept is important, its definition and terminology are confusing, because in the disaster management context it generally implies a return to the prior state after a natural disaster event (e.g. flooding). Manyena (2006: 433) notes that the term resilience has its origin in the Latin word resilio, meaning 'to jump back'. Provitolo (2013: 3) refers to such conflicting approaches in terms of a stable system regaining a state of permanent equilibrium (engineering resilience), versus a system moving towards different states of equilibrium (ecological resilience). Two typical ecologically based definitions of resilience appropriate to cities are:

> A resilient system is adaptable and diverse. It has some redundancy built in. A resilient perspective acknowledges that change is constant and prediction difficult in a world that is complex and dynamic … Resilience thinking is a new lens for looking at the natural world we are embedded in and the man-made world we have imposed upon it. (Ward 2007)

> A Resilient City is one that has developed capacities to help absorb future shocks and stresses to its social, economic, and technical systems and infrastructures so as to still be able to maintain essentially the same functions, structures, systems, and identity. (Resilient City 2013)

These definitions span the range of values embedded in resilience thinking that seeks to maintain existing structure in the face of shocks and change in perturbing the system. In *Resilient Cities,* Newman et al. (2009: 6) resilience is defined operationally with a specific reference to oil shortages as:

> Resilient cities have built-in systems that can adapt to change, such as a diversity of transport and land-use systems and multiple sources of renewable power that will allow a city to survive shortages in fuel supplies.

This definition refers to systems 'that can adapt to change', implying a change to a different state, and therefore implying a change in the urban metabolic systems that could result in a paradigm shift in resilience under new circumstances. Hence the term needs to be understood to imply not a bounce back, but a bounce forward towards a future state. This theme is also being taken up by the Transition Town Movement, which goes further to suggest that bouncing forward should be a transformation to anticipate and withstand the future potential shocks of energy, water and food security crises (Hopkins 2008: 134-136). Transition initiatives and other urban innovations are discussed in section 8.2. The notion of transformation as an adaptive framework is pertinent to the theme of oil-constrained cities in this chapter, as it also is to disaster management and climate change.

The terminology of transformation is therefore suggested to be the most relevant framework to use in this investigation of ideas pointing towards the oil-constrained city. Such a framework is based on the urban metabolism model developed in Chapter 1 with an ecological sustainability viewpoint and a regenerative approach. It addresses both our generation's capability to transform away from the expansionary pathways of development, and its obligation to maintain the opportunities for future generations. A transformed city will be resilient to natural resource depletion and to socio-economic challenges. The alternative continuous growth pathway threatens the Wallerstein and Diamond scenarios noted above. Because of the inherent uncertainties in oil reserves discovery and future economic extraction, together with demand being affected by future rising prices, the prudent planning approach is to adopt the precautionary principle approach and advocate a transformation strategy. Newman et al. (2009: 7-11) hint at this approach in summarising the rationale for reducing oil dependency to increase resilience in urban regions, as including five interconnected reasons:

1. reducing oil use is a political necessity;
2. reducing oil use will reduce impacts on the environment;
3. reducing oil use and investing in green buildings will reduce impacts on human health;
4. reducing oil use will result in greater equity and economic gain; and
5. reducing our dependence on petroleum fuels will make us less economically vulnerable to foreign oil and are likely to achieve more resilient, peaceful cities.

In summary, consideration of the concepts of sustainability and resilience on which this thesis is grounded lead to the conclusion that the more recent concept of transformation is the most relevant framework to use in this investigation. Transformation is postulated as being essential to the change process inherent in future oil depletion to adapting future urban design towards the conditions of an oil-constrained city. The potential impact of oil constraints on construction—and thus on the urban fabric—primarily affect urban design at the lot, precinct and neighbourhood scales, which would be reflected in the changing urban form. Such a conclusion should not be taken to presage the demise of cities, because history has shown the remarkable resilience and adaptability of human settlements. However, it does point toward a need to better understand and implement broad sustainability factors in this sixth wave and in future waves of innovation rather than continue a business as usual approach.

A key part of this research is to discover if some types of contemporary residential land development and building typology are more vulnerable to oil depletion than others, which may affect the sustainability of residential development in the medium to longer term. These issues will be increasingly important in managing the future growth and residential form of Australian cities.

The next section overviews how sustainable development theory and practice are being applied to urban population growth challenges in studies for the major cities of Perth and Melbourne, and the City of Gold Coast under the SEQ Regional Plan.

2.4 Australian urban growth management

The Australian Bureau of Statistics (ABS) projects the resident population to grow from 21.3 million in June 2008 to the order of 35.5 million (B series) by 2056 (ABS 2008b), which is a driver for this thesis research. The mid series B reflects ‘current trends in fertility, life expectancy at birth, net overseas migration and net interstate migration’. The range of Series A (42.5 million) to Series C (30.9 million) are based on high and low assumptions for each of these variables respectively. The major growth is projected to occur in the capital cities, accommodating an estimated 10 million more urbanites in this period, which would be similar to the growth during the whole of the twentieth-century. The ABS study also predicts growth rates in the capital cities in the medium term to be an average of 47 per cent between 2010 and 2031 (ABS 2008b). The ABS (2012) released the 2011 census and revised downwards the June 2011 resident population to 21.5 million, but maintained the growth projections in the broad range to 2056. This section gives two examples of strategic planning studies and a regional plan, which illustrate growth challenges at different scales of population, growth rates and infrastructure demands.

A National Urban Policy for a productive, sustainable and liveable future was released by the Australian Government (2011: 6) ‘to ensure that our cities meet the needs of current and future generations’. It confirms that ‘population growth over the coming decades is expected to be concentrated in our major cities' (2011: 10). The report (2011: 56) acknowledges that 'low density urban expansion has been the standard solution to accommodating population growth in Australian cities … On the other hand, simply infilling existing areas without improving the amenity for existing residents, is problematic'. While polycentric development is cited as one solution, creating more compact development around public transport corridors and activity centres is a complementary measure (2011: 56). The population growth forecasts require management policies by state and local governments for the major urban areas.

All the mainland capital city metropolitan regions have developed growth management plans (New South Wales 2005; Queensland 2009c; Government of South Australia 2010; State Government of Victoria 2002, 2008; Western Australia Planning Commission 2010). Other large cities, including the 550,000 population City of Gold Coast, have also developed growth management strategies (Gold Coast City Council 2010e). The more recent plans all emphasise planning responses to climate change and in that context seek to promote public transport and reduce greenhouse gas emissions from transportation. Yet until 2009, no planning strategy took into consideration the implications of an oil-constrained future, beyond a broad reference to future oil vulnerability, or rising petrol prices. Two growth management studies published in 2009 first set the scene on the problems of managing urban development to accommodate the projected population increases in the Australian metropolitan regions of Perth and Melbourne, as representing large and very large cities. The 2009 SEQ Regional Plan demonstrates the complexities of a polycentric metropolitan region in an evolving planning framework and highlights the planning for the City of Gold Coast.

2.4.1 Perth growth scenario study

The *Boomtown 2050: scenarios for a rapidly growing city* (Weller 2009) study by the University of Western Australia, led by Professor Richard Weller, was awarded for excellence by the Planning Institute of Australia. It grapples with the challenge of doubling the Perth population from 1.5 million to 3 million by 2050. This growth requires an additional 700,000 dwellings, reproducing the equivalent of the city's entire urban infrastructure that was constructed over 179 years, within 40 years (Weller 2009: viii). The study focuses on controlling sprawling suburban growth and puts it into stark perspective (Weller 2009: 30), suggesting that 'to sustain an individual (ecological footprint) in such housing now takes 14.5 hectares of land, seven times the world average. Western Australians, Saudi Arabians and Singaporeans share the increasingly dishonourable status of being the most unsustainable people on the planet' (Weller 2009: 30). In a business as usual approach to urban development, the Perth metropolitan area could become a 170 kilometre linear city covering over 200,000 hectares of the coastal plain. The question is posed as to whether private cars running on fossil fuels could service such a vast conurbation (Weller 2009: 185).

The pictorial survey of suburban development highlights sprawl and concomitant car dependence in a graphic way. On the basis that approximately half of the projected population increase could be accommodated in new suburbs providing 276,000 homes for 634,800 people (2009: 185), five alternative *horizontal* urban scenarios are conceptualised as 'POD City' (contemporary urban villages), 'Food City', 'Car Free City', 'Seachange City', and 'Treechange City'. The Car Free city concept relies on a grid of 800 metre spacing, supporting some form of public transport—rail, trams or buses—to promote walkable neighbourhoods of between 1,800 and 16,000 people (at 12 and up to 250 dwellings per hectare respectively) in mixed use development forms (2009: 291). The study then focuses on how to house the equivalent of a Paris population of 865,200 as infill development (needing 376,170 houses or 445,370 apartments) in a compact networked city (2009: 313, 318). It poses a variety of densified *vertical* scenarios categorised as 'Sky City', 'River City' and 'Surf City'. All the scenarios are shown in a composite diagram as 'Divercity' (2009: 390) reproduced in **Figure 2.9**

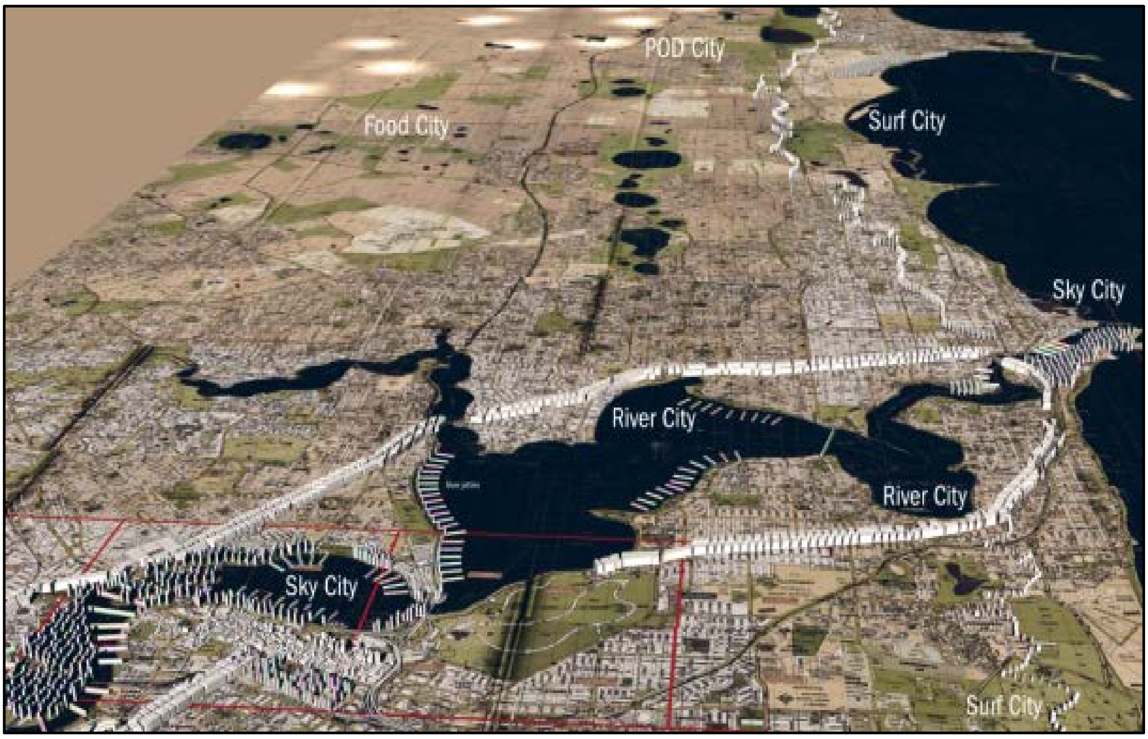


Figure 2.9: Perth development scenarios

Source: Weller (2009: 390) with permission

The diagrammatic concept highlights the vertical solutions as dominating the inner city and coastal skylines. The study does not detail the horizontal solutions much beyond the white circular patches of POD city urban villages stretching the overall metropolitan area. The study acknowledges the difficulty of persuading residents imbued with a suburbanite lifestyle to change to high density living, even if it means grossly extending the urban footprint and perpetuating car dependency. Such a business as usual approach would result in Perth being among the world's largest cities with the lowest urban density, considered to be 'an ecological and social nightmare' (Weller 2009: 395). While the study links the diverse urban forms to the public transport network, including the expanded rail infrastructure, the principal author (Richard Weller pers. comm. 27 November 2009) acknowledges that the impacts of future oil depletion had not been fully factored into the future scenario models. The study does not go into any detail on the provision of urban infrastructure to support the mainly architectural concepts, beyond concerns about low density housing form and construction that currently rely heavily on the oil economy.

A contemporary demographic analysis of Perth greater metropolitan area growth in population and patterns of development by the Western Australian Planning Commission (WAPC) considers a single scenario—the network city—to accommodate another 1 million people in 600,000 dwelling units (WAPC 2008: 3). The study maps how the 32 local government areas (LGAs) might grow in the period 2007-2050. The trends are for small (1-2 people), younger and older households to move to central Perth and the inner suburbs—if they can afford to. New forms of residential development are needed to 'make fuller use of the urban land … and provide affordable housing' as alternatives to fringe dormitory suburbs (2008: 15). The study suggests distributing growth by LGA between major and minor infill and greenfield development in a prescriptive scenario based approach. The study accepts the need for better public transport in existing suburbs, networked into larger urban centres. It does not make any specific recommendations as to the type of development, nor take into account future oil constraints beyond a passing reference to time and costs of travel.

As a postscript to the Weller study, Weller and Bolleter (2013) led a much wider study that looks ahead to growth in the eight capital city regions to 2101. It builds on some of the foundational thinking from the *Boomtown 2050* study to see how to accommodate an additional 39,400,000 in those cities as the nation grows to 62.2m. This is equivalent to adding 24 cities the size of Perth, or 10 Melbournes (2013: 21). The study notes that strategic plans for the major cities show some 40 per cent of growth as greenfield development; yet the designated other 60 per cent infill housing is only achieving approximately 30 per cent—much of that as small scale inner suburban conversions from detached houses up to six dwelling units per lot (2013: 56).

It should also be noted that the City of Stirling within the Perth metropolitan region is one of the few Australian municipalities to implement an Oil Risk Strategy 'to plan and implement proactive measures that reduce and, in the long term, eliminate Stirling's dependence on crude oil. This is a highly complex and challenging goal, but it can be done as long as all levels of government co-operate and bring the community and industry into a rapid de-oiling of the economy' (City of Stirling 2012: 9). The strategy recommends five sets of measures that the City could take independently of policies at state and federal levels of government, affecting the council or community:

1. measures that reduce the number of kilometres that people and goods travel;
2. measures that reduce or eliminate the use of oil in personal and freight transport;

3. measures that enable Stirling to be less reliant on external sources of electricity derived from fossils fuels, because stationary power is integrally connected to oil use in transport;
4. measures to inform and engage residents, businesses and Council personnel in successfully dealing with the peak oil challenge;
5. the creation of a contingency plan setting out steps to be taken to reduce the pain and disruption of peak oil if the City has not taken proactive measures in time. (City of Stirling 2012: 11).

Some of these strategies are explored in Chapter 6—in search of the qualities and common elements that characterise a sustainable city.

2.4.2 Melbourne growth study

The Melbourne study *Transforming Australian cities for a more financially and sustainable future* was jointly commissioned by the Victorian Department of Transport and the City of Melbourne to examine the potential to transform metropolitan Melbourne for a projected population from 3.8 million in 2007 to 5.0 million by 2029 (Adams 2009). The study was awarded the Australian Urban Design prize in 2009. The study focuses on housing and infrastructure provision to accommodate an additional 840,000 people in 600,000 dwellings at 200 people per hectare (2009: 13), taking into account climate change and diminishing fossil fuels (2009: 9). Infill development in activity centres and along transport corridors is advocated to take pressure off *ad hoc* redevelopment in existing suburbs. While the study addresses the issue of affordability and suggests a saving of $300 million per 1000 houses by infill development (2009: 16), it acknowledges the challenge to gain public acceptance of such a policy.

The study was informed by the *Metropolitan Strategy: Melbourne 2030 - Planning for Sustainable Growth* (Victorian Government 2002, 2008a), which was introduced in 2003 as a 30-year plan to manage the population growth of metropolitan Melbourne. The 2003 plan has been criticised by community groups including Save Our Suburbs Inc. [Vic] (SOS), an organisation 'devoted to protecting citizens from the destruction of their houses, their streets, and their environment' (SOS 2003: 8). SOS criticised the plan for seeking to promote higher density housing in established suburban locations in a way that would not 'preserve the amenity and rights of existing residents' or 'enhance the character of Melbourne's suburbs' (SOS 2003: 8). The alternative SOS vision is that:

> Melbourne should retain its incomparable suburban environments, but should incorporate within this fabric concentrations of higher density development, clustered around nodes of public transport and provided with retail outlets, job opportunities, and educational and cultural facilities … SOS believes that greater densities can and should be achieved without adversely affecting existing residents, and with better quality results than at present. We believe for example that greenfield sites are the priority locations for high density housing (SOS 2003: 8).

The SOS reasoning is that greater certainty would be achievable for new planned suburbs incorporating high density housing, rather than *ad hoc* infill development of existing inner suburbs. In fact the Adams study also shuns this *ad hoc* approach. The views expressed by SOS and reiterated in a more recent critique of the 2030 plan (SOS 2007) are reflective of neighbourhood groups opposed to the densification of inner and middle suburban areas in major Australian cities. These community views generally create obstacles for the implementation of growth management plans.

The Melbourne study (Adams 2009: 28) takes an urban transit corridor and activity centre approach to urban development as the means to direct growth. The study advocates that such corridors and activity centres that together account for only 6% of the land area within the urban growth boundaries, 'would need to become known as the most desirable locations for new urban development' (2009: 13). The corridor approach is supported by Woodcock et al. (2009) and would be developed as medium rise (4-8 storeys) high density transit corridors. This concept, shown at page 28 of the report, is retrofitted to the northern arterial Sydney Road from the CBD to Coburg locality. The diagram is at **Figure 2.10**. In the context of this research, that solution assumes corridor development could be constructed, as well as having a high degree of acceptance of such an urban lifestyle, amid continual disruption of existing residents by redevelopment project operations in the activated corridors.

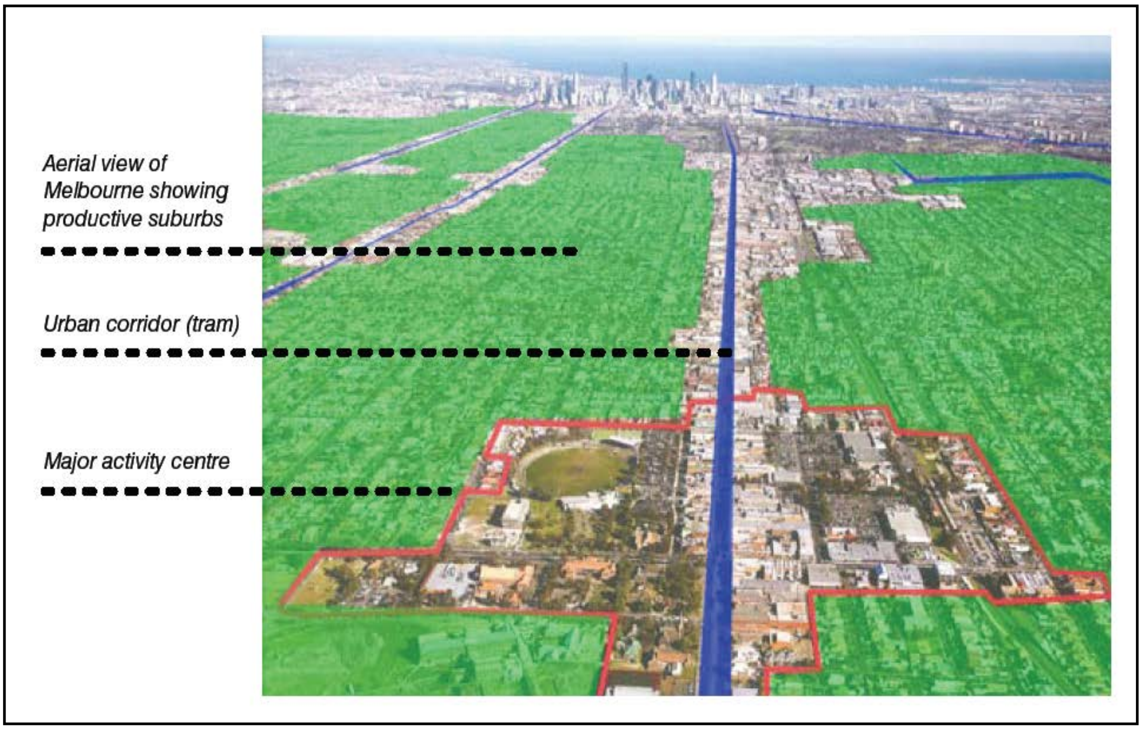


Figure 2.10: Melbourne corridor development concept

Source: Adams (2009: 28) with permission

The Melbourne study, like the 2009 Perth study, does not go into detail on the provision of urban infrastructure, currently relying on the oil economy. However, it does address the sustainability of suburban development to take into account the concerns expressed by groups such as SOS. Existing suburban interiors would become the productive new 'green wedges of our future cities ... to reduce the overall ecological footprint of the city, making it more sustainable' (2009: 27). Some of the visionary benefits of such productive suburban lots hark back to the early twentieth century near-utopian conditions described by Forster (2004: 10) and Davison (2006: 205) and espoused by Troy (2003: 117), wherein 'the suburban house and its garden provide the stage on which most Australians lived their easy-going lives of comfort in reasonable balance with nature'. From an environmental sustainability perspective, suburban homes 'become less consuming of energy and water and each household becomes more self-sufficient', generating renewable electricity, harvesting rainwater, growing food and aiding carbon sequestration (Adams 2009: 31).

In contrast, the City of Maribyrnong 8 km northwest of Melbourne CBD has published an oil contingency plan for council business continuity and community awareness relative to short term disruption and long term oil decline (Fishman et al.2009). Planning measures include transport and food security (the suburban homes ideas noted above). These are similar to the Stirling plan (section 2.3.1) and are revisited in Chapters 6 and 7.

2.4.3 The evolving South East Queensland Regional Plan

This section introduces the South East Queensland (SEQ) region of 3 million population that was defined in 2001 with the development of the initial SEQ 2001 Regional Framework for Growth Management (Queensland 2001). Prior to that time, there was effectively no state direction on strategic planning of what was, and continues to be, among the fastest growing regions in Australia. Growth pressures in coastal communities such as the City of Gold Coast were such that development occurred in advance of formal planning. The resulting SEQ Regional Plan 2005-2026 became the first state planning instrument giving direction to SEQ local governments and providing the statutory head of power for planning at the regional scale (Queensland 2005). Its overriding intent was the sustainable growth of the region in ways that supported a compact, well serviced and efficient urban form. The failure of local government planning schemes to constrain residential sprawl under earlier planning legislation was addressed by introducing the urban footprint concept. The designated urban footprint was intended to promote compact urban forms within a defined urban footprint area. However the region generally faces similar infrastructure pressures as Perth in providing adequate and affordable residential accommodation.

A revised SEQ Regional Plan 2009-2031 (Queensland 2009c), covers 11 sub-regional and city local government areas, as indicated in **Figure 2.11**. It predicts the region to grow from 2.8 million residents in 2006 to around 4.4 million in 2031 (2009c: 91). Some 754,000 new dwellings will need to be built in SEQ over the 25 years from 2006 to 2031 'through a mix of additional development in existing urban areas and on broad hectare land' (Queensland 2009c: 9). The growth forecasts equate to some 6.5 new dwellings for every 10 existing dwellings in the region, at a minimum net dwelling yield of 15 dwellings per hectare. The greenfield growth is intended to be accommodated in 23 designated regional and local development areas indicated by purple dots in Figure 2.11**,** under a complex process of state and local government developed structure plans for declared master planned areas.

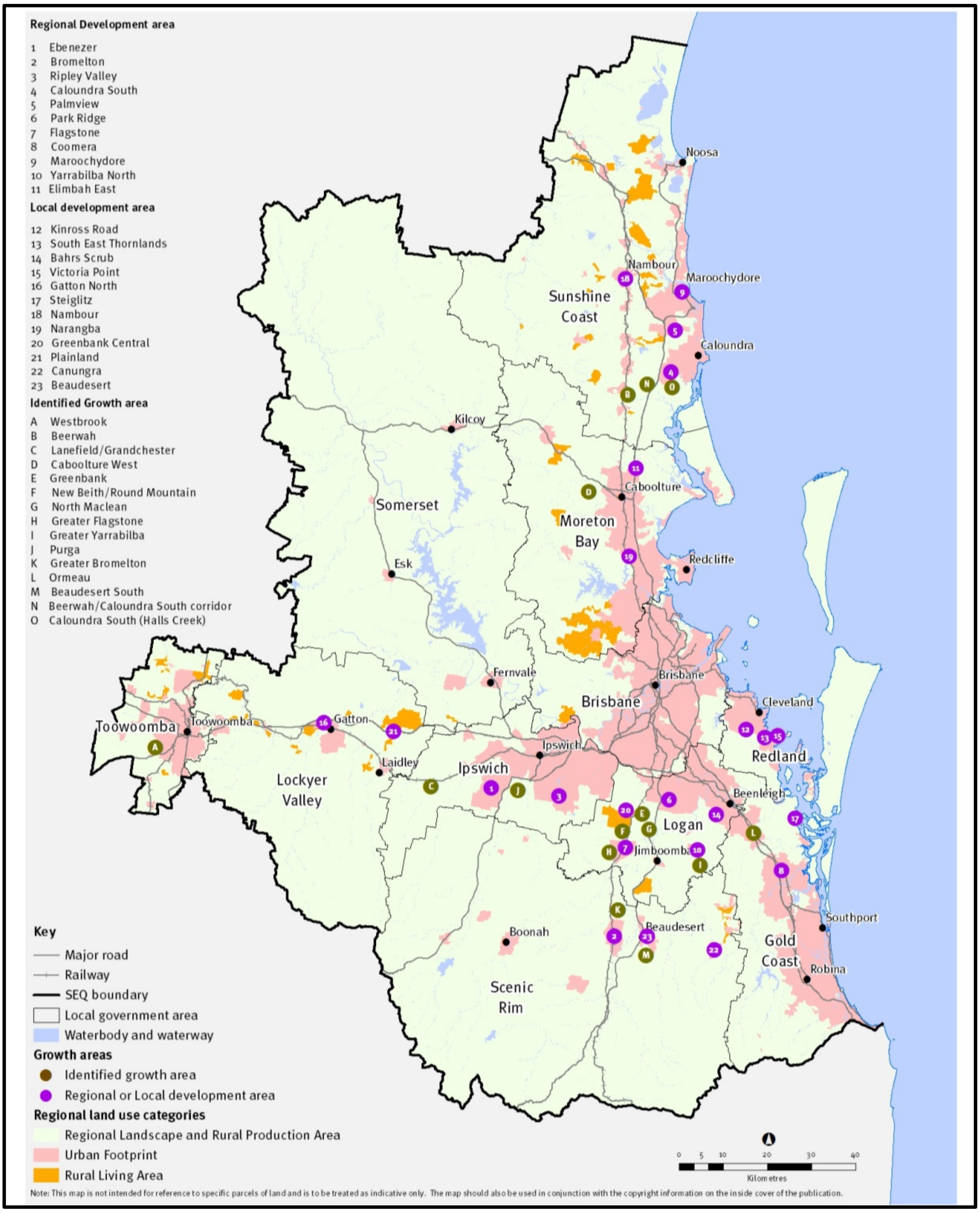


Figure 2.11: SEQ regional planning identified growth areas as at 2009

Source: SEQ Regional Plan 2009-2031 Map 12 (Queensland 2009c: 108)

Local governments were allocated responsibility for achieving the targets shown in Figure 2 of the Regional Plan report (2009c: 9), reproduced at **Figure 2.12.** In 2010, the Queensland Government held a growth management summit with environmental and planning experts, development industry groups and the community to explore growth scenarios and find alternative solutions to lessen the population impact on SEQ. The state response included a commitment to 'work in partnership with local government to confirm the distribution of the dwelling targets within SEQ through the development of a Queensland infrastructure plan' (Queensland 2010c: 6).

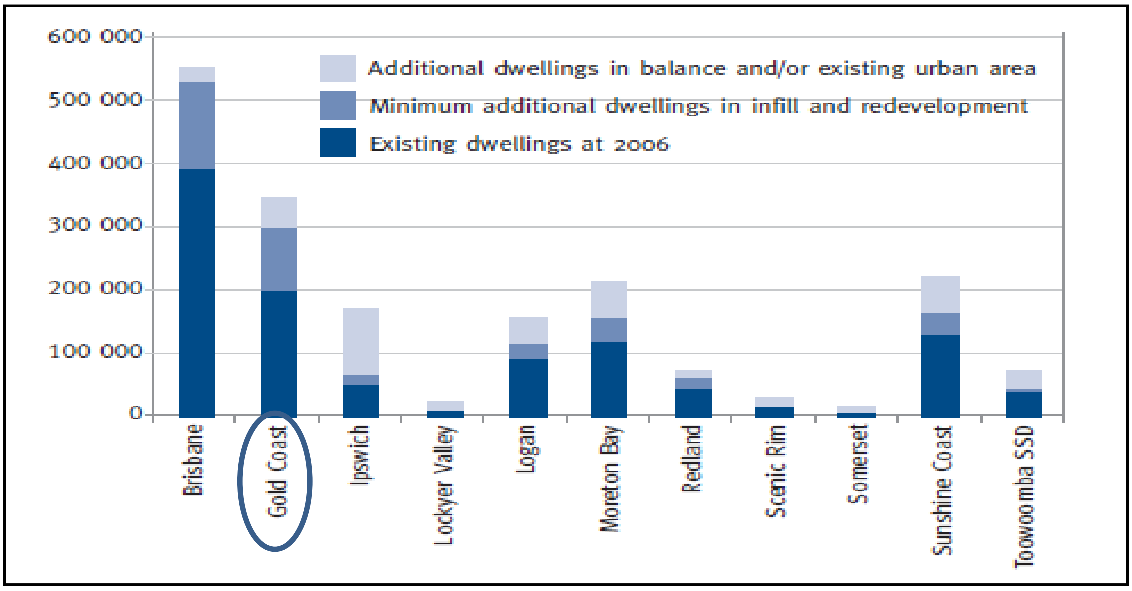


Figure 2.12: South East Queensland existing and planned dwelling distribution by local government area 2006-2031

Source: Queensland Government (2009c: 9)

A change of state government in March 2012 to an LNP government cut short this dialogue. The new policy direction for development and planning focused on a 'four-pillar' economic model—to promote mining, agriculture, tourism and construction—that included greater devolution of planning to local government, with less state coordination. One of the model's key elements set out in the 2013 State Planning Policy was to promote construction activities through planning that 'supports a thriving industry that is both a major employer, delivers the housing we need and is a prerequisite for other economic activities', including by: 'identifying suitable land for residential, commercial, retail and industrial development, and providing a mix of zone types and locations that consider existing and anticipated demand'; and considering the use of government land suitable for infill and redevelopment opportunities' (DSDIP 2013B: 22). Consideration was to be given to eliminating the policy of urban footprints.

The Urban Land Development Authority (ULDA) was established in 2007 to help make housing more affordable and to deliver a range of housing options for the changing needs of the community. The ULDA controlled development in four of the Regional Development Areas in SEQ shown in Figure 2.11 (ULDA Act 2007). However, the whole system changed in 2012–13. In mid-2012 the new LNP government started to hand back the ULDA projects in SEQ to the local governments, but found the ULDA Act prevented full devolution of planning powers (Hopgood & Gamin 2012). Instead the ULDA was reconstituted under a new *Economic Development Act 2012* as Economic Development Queensland and it continues to plan and develop land for residential and industrial purposes, both in SEQ and in the resource regions of the state, in designated priority development areas. This has become significant for the Gold Coast Southport area. In mid-2013 the state amended the *Sustainable Planning Act 2009* to cancel structure plans and declared master planned area requirements. New planning legislation to underpin the planning reforms was announced, with a new generation of regional plans, including an overhaul of the SEQ Regional Plan, to be led by the Department of State Development, Infrastructure and Planning (DSDIP 2013a). These evolving planning aspects are addressed in more detail in section 4.3 in relation to the moderating planning factors of the conceptual framework[9].

The relevance of these changes for SEQ in relation to urban growth management is that planning and development are influenced by an accelerating pace of change in the whole system. Between 1997 and 2016, local governments will have been subject to four significant changes of policy direction in both state planning legislation and in regional plans. While the still current 2009 SEQ Regional Plan does recognise that an increasing vulnerability of oil supply may progressively affect liveability and affordability in SEQ (Queensland 2009c: 11), the future policy direction is uncertain. The Sunshine Coast Regional Council (SCRC) published a Climate Change and Peak Oil Strategy 2010-2020, which provides a framework similar to the City of Stirling strategy (SCRC 2010: 3).The new economic policies foresee a renewal of the underlying assumption of a business as usual approach to developing land and the built environment. However, even the current 2009 SEQ Regional Plan skirts around the issue about how an increasing oil supply vulnerability may impact SEQ as a whole—or on particular local government areas—in terms of potential development constraints. Figure 2.11 indicates that most of the designated growth areas are on the edge of the urban footprint (3, 4, 5), or worse, in remote areas (7, 10, 17). The latter suggest the development of completely new towns. Such analysis has been left to Economic Development Queensland and the 11 local governments. One of the sub-regional areas is the reference City of Gold Coast.

Gold Coast City growth management and planning scheme review

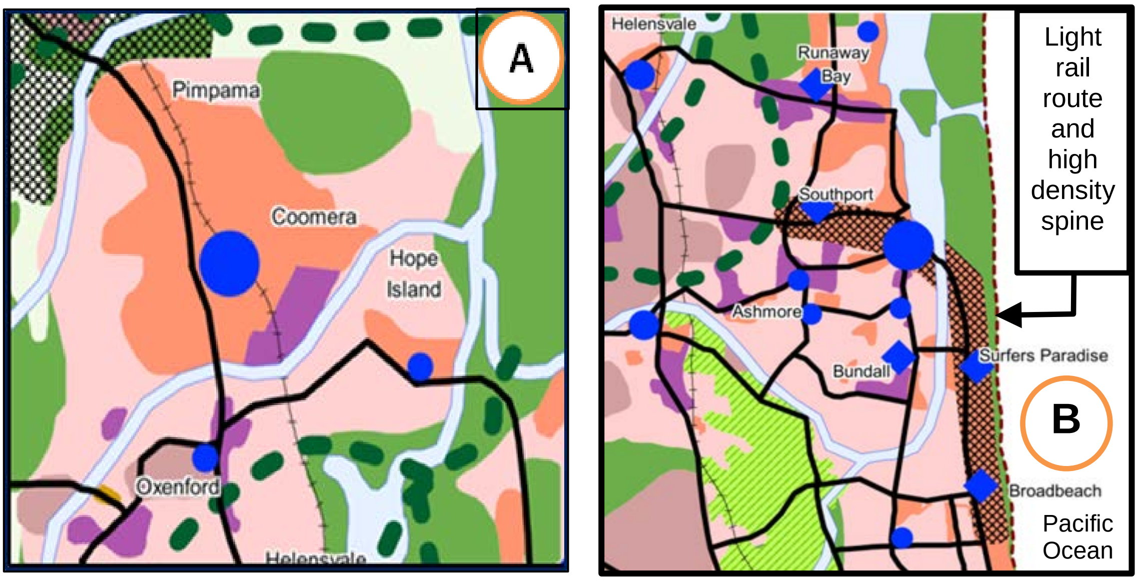
As an example of the SEQ growth studies, the Gold Coast City Council (GCCC) (2010e) responded by designating development targets for particular growth centres such as the long established Southport area over the next 20 years (Figure 2.4B). An extreme scenario could be a high rise solution to provide all of the 19,500 required dwellings. The research for this thesis estimates the order of 195 25-storey towers (at 100 units per tower) would be needed—spread over sites totalling about 125 hectares of some 300 hectares available for redevelopment—an urban forest of tower buildings. Since the 2010 study, the draft Central Southport Master Plan proposes a much lower increase of 20,000 *people* with a focus of redevelopment around rapid transit stations at

[9] In early 2015 after completion of this thesis, the state government changed–reverting to the Labor Party that had developed the 2009 SEQ Regional Plan. The new government reversed major policy changes and is in the process of gaining Parliamentary approval for a new planning Act in mid-2016.

dwelling densities of up to 120 per hectare (GCCC 2012). This would still require 7-10,000 dwellings to accommodate the increase.

The Gold Coast City Transport Strategy 2031 (GCCC 2013c: 5) strongly advocates a public and active transport focus to handle future travel demand rising from 2.6 million daily trips in 2011 to 3.75 million in 2031. Yet car trips are forecast to increase in the 20-year period from 2.286 to 2.771 million, even with a reduction from 87.9 to 74 per cent of the total trips. Reducing future oil supply vulnerability receives only passing references in the supporting technical report (2013d: 10). An oil mitigation strategy has been in preparation for the city, but has not been released as at late 2015, nor has it been included in the transport strategy.

The GCCC commenced a review of its planning scheme in 2010 and submitted a preliminary draft planning scheme to the state government in February 2012 (GCCC 2012). The draft strategic framework plan is shown in Figure 2.4. **Figure 2.13(A)** reproduces the Coomera-Pimpama area as the last major greenfield area, which is promoted as a 'transit supportive neighbourhood', focused on the Coomera rail station and proposed town centre (large blue spot). The Southport-Broadbeach strip (**Figure 2.13(B))** is set to be redeveloped as a high density residential spine along the light rail line, although much of it east of the Nerang River is fully developed with apartment buildings. After the local government elections in April 2012, the draft scheme was withdrawn for major revision to accord with the new council's policy directions on economic growth. The revised scheme was not released prior to completion of this thesis, and was likely to be further delayed by the state government planning reforms. Hence the 2003 planning scheme, modified by relevant changes in the draft 2015 *City Plan* scheme[10], is used as the basis of this research in Chapters 4, 5 and 6.



[10] Since completion of the thesis, the new 'City Plan' commenced on 2 February 2016, with essentially the same strategic plan and growth strategies for Coomera and the Southport-Broadbeach high density spine.

Figure 2.13: Gold Coast draft 'Bold Future Planning Scheme' settlement pattern: A - Coomera growth area; B – Southport-Broadbeach redevelopment area

Source: Gold Coast City Council (2012) with permission (not to scale)

2.4.4 Conclusions on urban growth management studies

The ABS projects the resident population to grow from 21.3 million in 2008 to the order of 30.9 – 42.5 million by 2056 (ABS 2008b). The major growth is projected to occur in the major cities, accommodating an estimated 10 million more urban and suburban dwellers in this period, which would be similar to the national growth during the whole of the twentieth-century. Recent growth management plans emphasise planning responses to climate change, and in that context, seek to promote public transport and reduce greenhouse gas emissions from transportation. Yet as of 2014, no metropolitan planning strategy had taken into consideration the implications of oil depletion, beyond a broad reference to future oil vulnerability, or rising petrol prices.

Consideration of oil vulnerability effects only as rising costs of private transport is a weakness inherent in these and similar planning studies. Public and active transport strategies are being proposed to improve urban mobility and health in compact city urban forms and to mitigate global warming. Yet the strategic planning scenarios assume a continuing business as usual approach to constructing urban infrastructure and the necessary facilities to support urban living. Although governments advocate compact city form, there has been a counter culture resisting this form by celebrating suburbs to improve existing suburban lifestyle by nodal transit oriented development. It is mainly in alternative 'green' building or 'sustainable' assessment guides that there is recognition of, and support for, using natural materials and processes that could reduce oil dependency (Wheeler 2004; Towers 2005; Etchetto 2008; Kats 2010). Some alternative guides tend to look back to the pre-oil economy for inspiration in urban design (Alexander et al. 1977; Barton 2000; Kennedy et al. 2002).

Neither of the growth studies for Perth or Melbourne is overtly cognisant of the potential for future oil constraints to have a significant impact on the ability to construct the proposed medium-high density residential development, relied upon in compact high-rise transit oriented network city forms. Yet an oil depletion scenario is relevant to the current 20 year spatial planning strategic horizon, as acknowledged in the (Perth) City of Stirling Oil Risk Strategy, (Melbourne) Maribyrnong Plan and the (Queensland) Sunshine Coast Regional Council strategy. What is made evident or implied in those studies and in the current 2009 SEQ Regional Plan is:

1. a more compact city form is essential to accommodate population growth, predominantly as medium-high density infill development;
2. promotion of a reduction in private motor car use;
3. reduction in the need for daily work commuting;
4. strong support for improved public and active transport;

5. the imperative to reduce greenhouse gas emissions—thereby mitigating climate change impacts—to improve urban sustainability.

All the referenced studies take an urban transit corridor and activity centre node approach to urban development as the best means to direct growth, which reflect the National Urban Policy principles. All the cited studies consider that pursuing suburban sprawl will be unsustainable, mainly because of oil dependent transportation, despite the contrary views of action groups such as Save Our Suburbs advocating more greenfield suburbs. This strategy is supported by Newman et al. (1999, 2009), Yencken and Wilkinson (2000), Dodson and Sipe (2006, 2008b, 2008c) amongst several others, who express concerns about the continuing sprawling sub-urban form, both in Australia and elsewhere. Nevertheless divergent views remain in support of the utility and amenity of suburban living (Chiras & Wann 2003, Troy 2004, Davison 2006). The Weller and Bolleter study (2013) takes a fresh perspective to longer term growth in the eight capital city regions to 2101. The study notes that strategic plans for the major cities show some 40 per cent of growth as greenfield development; yet the designated other 60 per cent infill housing is only achieving approximately 30 per cent—much of that as small scale inner suburban conversions from detached houses up to six dwelling units per lot (2013: 56). The exploratory graphic presentation of new development required in each city indicates a fundamental shift towards higher density forms, necessitating large scale medium–high rise residential infill buildings.

2.5 Conclusions on Australian urban growth context

This chapter has addressed research objectives 1.1 and 1.2 on how oil dependency and possible future oil depletion may relate to sustainable development and construction factors in urban residential development and consequential urban form. The exploratory literature investigates relationships between sustainable urban residential development and possible oil dependency in the Australian context. It includes urban development, sustainable cities and related concepts, and urban growth issues.

Urban development context

In relation to the urban development context, the literature shows that prior to the motor car era, cities were essentially walkable enclaves, albeit with horse-drawn carriage transport. In the twentieth- century inter-war years, an acceleration of outward movement of both residential and industrial development led to an explosion of the urban land areas in Australian, American and northern European cities as part of the phenomenon termed suburban sprawl. The transformation from the star-shaped public transport (transit) based city radiating from a dominating city centre to the polycentric form of the ‘auto city’, was clearly apparent by the 1960s. Suburban expansion has been at the heart of urban growth in all major Australian cities, as opposed to a compact European urban setting. In more recent planning policies advocating more compact city form, there has been a counter culture to celebrate the broader social and environmental values of suburbs and to improve suburban lifestyle with transit oriented development and social spaces.

Defining urban form

Urban form can be conceptualised as a geographical transect, depicted as a sequence of building scale and density from each central business district through the adjacent inner urban and low density outer suburban areas to describe the urban morphology. The thesis research has taken into account the multiple urban planning and design sources to offer a comprehensive definition of urban form in the Australian and more general planning context as a first contribution of this thesis:

> Urban form is a set of complex relationships comprising: the development patterns and spatial structure in a hierarchy of scales (the urban fabric); the height, shape, density and appearance of the built environment; the interface between the built environment and public realm (streets and public spaces); movement hierarchies, networks and transport systems; public and private open space; developed within the historical, geographical, ecological and climatic context. This definition could be extended to depict urban form as arising from—and supporting, facilitating and sustaining—the socio-economic functionality of a city, including social and cultural processes, metabolic flows of substances, goods, energy and communication.

While the existing and planned urban form provides the morphological setting, the buildings themselves are the products of technological design and construction processes, with varying quantities of renewable and non-renewable materials, each having different embodied energy. Every residential building type has a characteristic identity, which is generally related to the manner of attachment (whether side-by-side or stacked); height in storeys/levels and floor area (Australian Government 2008). A key aim of this thesis is to discover if some contemporary residential land development and building typologies are more vulnerable to oil depletion than others. If this were the case, it might affect the sustainability of development in the medium to long term and hence the urban form, which is identified as the ultimate dependent condition in the conceptual framework in Figure 1.3. The current urban residential typology relevant to Australian circumstances and the reference City of Gold Coast is broadly identified as:

a. Detached and semi-detached houses of 1-2 storeys (the predominant suburban style)
b. Attached town (row or terraced) houses, and apartments (2-3 storeys) above parking; typically with individual heating ventilation and air-conditioning (HVAC) systems
c. Medium rise, medium density apartments (4-8 storeys) with lifts (elevators) and typically with integrated HVAC systems
d. High rise apartment towers above 8 storeys with lifts and integrated HVAC systems.

Sustainable and resilient cities concepts

The chapter discusses the concepts and terminology of sustainability, resilience, regeneration and transformation as the foundation for the cities of the future. The twentieth-century oil economy could be shifting irreversibly in this century towards a different paradigm of transport and static energy sources and possibly to radically different economic and technological conditions. According to some analysts, such conditions could possibly lead to the collapse of societies that continue to rely on fossil fuels and use these and other resources unsustainably (Diamond 2005; Heinberg 2007; Slaughter 2010; Gilding 2011). This thesis investigates those claims and how future prospects of petroleum supply constraints might gradually affect residential (and other) building types; to influence an urban design transformation from dispersed towards more compact city forms in the future oil-constrained city. The concepts about sustainability have been widely debated and used in planning and environmental literature (Wheeler 2004: 20-23). Sustainability is essentially linked by the change process inherent in future oil depletion to adapting future urban design in terms of building types, density and structure. The potential impact of oil constraints on construction—and thus on the urban fabric—primarily affect urban design at the lot, precinct and neighbourhood scales, which may be reflected in the changing urban form. The terminology of sustainability and resilience leads to the conclusion that the concept of transformation is the most relevant framework to use in this investigation of ideas pointing towards the oil-constrained city. Such a conclusion should not be taken to presage the demise of cities, because history has shown the remarkable resilience and adaptability of human settlements. However, this thesis is premised upon the notion that the twentieth-century oil economy is shifting irreversibly in this century toward a different paradigm of motive and static energy sources and possibly to radically different economic and technological conditions. If this is the case, it may affect the sustainability of new residential development in the medium to long term, and hence the urban form. These issues will remain important in the future growth and form of Australian cities.

Australian urban growth issues

Two growth management studies published in 2009 set the scene on the problems of managing urban development to accommodate the projected population increases in the Australian metropolitan regions of Perth (1.5 million) and Melbourne (4 million), as representing large and very large cities. A review of the South East Queensland Regional Plan 2009-31 demonstrates the complexities of a 3 million polycentric metropolitan region in an evolving planning framework and details the planning for a sub-region—the 550,000 population City of Gold Coast. A weakness inherent in these and similar planning studies is that vulnerability to future oil depletion is recognised mainly in relation to its effects on rising operating costs of private transport. Public and active transport strategies are being proposed to improve urban mobility and health in compact city urban forms and to mitigate global warming. Yet the strategic planning scenarios assume a continuing business as usual approach to constructing urban infrastructure and the necessary facilities to support urban living. It is mainly alternative 'green' building or 'sustainable' assessment guides that there is recognition of, and support for, using natural materials and processes that could reduce oil dependency. Some alternative guides tend to look back to the pre-oil economy for inspiration in building materials and urban design.

All the referenced studies take an urban transit corridor and activity centre node approach to urban development as the best means to direct growth, which reflect the National Urban Policy principles. All the studies consider that pursuing suburban sprawl will be unsustainable, mainly because of oil dependent private transportation, despite the contrary views of action groups such as Save Our Suburbs advocating more greenfield suburbs. A more recent exploratory study of new development required in each city indicates a fundamental shift towards higher density forms, necessitating large scale medium–high rise residential infill buildings (Weller & Bolleter 2013). Divergent views therefore remain between the desirability of compact form and suburban living. While the current 2009 SEQ Regional Plan does recognise that an increasing vulnerability of oil supply may progressively affect liveability and affordability in SEQ, the future policy direction is uncertain. The new economic policies foresee a renewal of the underlying assumption of a business as usual approach to developing land and the built environment. Neither the growth studies for Perth and Melbourne, nor the 2009 SEQ Regional Plan are overtly cognisant of the potential for future oil constraints to have a significant impact on the ability to construct the proposed medium-high density residential development, relied upon in compact high-rise transit oriented network city forms. Yet an oil depletion scenario is relevant to the current 20 year spatial planning strategic horizon, as acknowledged in the City of Stirling Oil Risk Strategy, the Maribyrnong Oil Contingency Plan and the Sunshine Coast Regional Council Climate Change and Peak Oil Strategy 2010-2020.

Working propositions for Part 1 question

The chapter findings reinforce the concerns already raised about climate change impacts of transportation and the significance for sustainable urban form, in particular for new urban development. The overall findings suggest working propositions for the Part 1 research question that:

1. *Relationships between urban residential development in the Australian context and oil dependency exist.*

2. *Such relationships may be significant in the growth of major cities.*

The first proposition is supported by the insights gained in this chapter that:

a. Suburban expansion has been at the heart of urban growth in major Australian cities, as opposed to a traditional compact urban form.

b. The dominant suburban forms of residential development have been influenced significantly by the availability of all forms of oil-powered transport.
c. In more recent planning policies advocating more compact city form, there has been a counter culture tending to celebrate suburbs and improve existing suburban lifestyle by isolated transit oriented development nodes, which effectively acknowledges the continuing oil dependency relationship.

The second proposition is supported by the insights gained in this chapter that:

a. There is support in the literature for the construct that buildings are the products of technological design and construction processes, with varying quantities of renewable and non-renewable materials, each having different embodied energy. Chapter 3 will demonstrate how petroleum (oil and gas) dependency is evident or implied in the resource and energy inputs.
b. The oil-related transport and construction issues affecting urban form will remain important in managing the future growth of major Australian cities and constructing the required infrastructure, including in the reference City of Gold Coast.
c. The significance in the relationship is qualitatively established and will be quantified in Chapters 3 and 5.

Chapter 3 of Part 1 research will investigate the significance aspect of the relationship between the oil-related aspects of constructing urban infrastructure and sustainable residential development and highlights the reasons why it is important to investigate this problem. **Figure B** shows the relationships in Part 1 of the thesis.

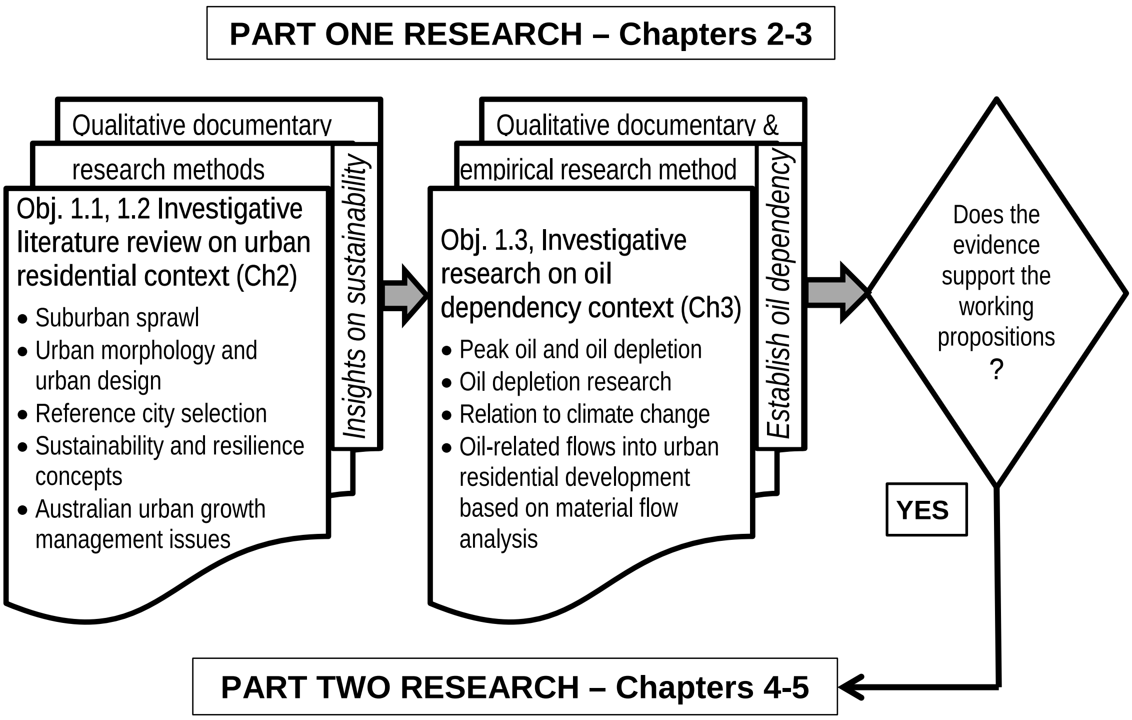


Figure B: Part 1 chapter 3 research design summary

Chapter 3

Dependency of urban development on petroleum

> *The modern city is a 'Petropolis': all its key functions—production, consumption and transport—are powered by massive daily injections of fossil fuels. But there is growing evidence that the resulting dependencies are ecologically, economically and geopolitically precarious, particularly since fossil fuel supplies which modern cities depend on are finite.* (Herbert Girardet et al. 2013: 8)

The working propositions suggested by the literature review findings in Chapter 2 are further investigated in this chapter to determine the significance of the dependency relationships urban residential development to petroleum (oil and gas)[11]. The chapter reviews current research and analysis to demonstrate the extent of oil dependency as an emerging global wicked problem, the global peak of production and timing, and some implications of oil depletion for urban development. The considerations include oil supply vulnerability strategies in a comparison between oil depletion and climate change. The urban metabolism theory used to develop the initial conceptual framework in Chapter 1 is applied with material flow (partial life cycle) analysis to provide a description of the oil and gas inputs, the details of which are in **Appendix B.**

3.1 Oil dependency and peak oil

Petroleum is a precious non-renewable substance. Dilip Hiro contends in *Blood of the Earth* (2007: 332), 'there is no historical precedent for a single mineral coming to dominate human life as completely as petroleum since it was first extracted in commercial quantities in the mid-nineteenth century'. This section analyses current research to demonstrate the extent of oil dependency, the global peak of conventional oil production, and some implications of oil depletion for urban development.

3.1.1 Oil dependency as a global wicked problem

Petroleum, as oil and gas, is not only fuel for electricity generation, motorised vehicles and machines (including industrialised food production), heating and cooking, but also is feedstock for fertilizers, pesticides and petrochemicals ranging from plastics and rubber to synthetic fibres, surface coatings, glues and additives of all kinds (Wittcoff et al. 2004). Its heavy fraction bitumen (asphalt) surfaces roads and waterproofs buildings and boats. It has become fundamental to every facet of modern civilisation.

As noted in section 1.1, Droege (2006: 160) contends 'it is difficult to overstate the significance of black gold in defining virtually everything that cities are today: spatially, economically and culturally'. Richard Heinberg (2007: 7) asserts 'for the past 200 years, cheap, abundant energy from fossil fuels has driven technological invention,

[11] Petroleum is the generic term for all hydrocarbon oils and gases (see glossary). In this thesis the focus is on the oil component, with inclusion of gas where appropriate, hence the term 'oil' is mainly used.

increases in total and per capita resource extraction and consumption (including food production), and population growth'. 'Oil is the world's single largest traded commodity, accounting for over half the total value of all commodity transactions' (ODAC 2012). The complexities of the economic, social and environmental consequences of oil dependency extend well beyond the urban development conclusions in section 2.5 into every facet of modern society and technology as an emerging *global wicked problem*. It is only *emerging* since the mid-2000s when global demand forced prices to record high levels. Prior to that time, apart from the 1973 crisis, oil was traded at relatively stable prices.

Two key concepts for beginning to understand global problems both in general and specific cases are *wicked problems* and *social messes*. Richard Tanter (2009), Project Coordinator of The Global Collaborative, a project of the Nautilus Institute, writes about global wicked problems. The following explanations are worth quoting at length:

> *Global problems* are not just important problems, or problems that affect many people. Rather they are those problems that affect the whole of the planet, and potentially all of the people who live on it … Examples of global problems of this scale and with these characteristics would include climate change and resource depletion, especially that of energy resources, on a scale and in a manner that are both unsustainable and profoundly inequitable … Their character and inter-dependence is such that they can only be solved jointly and simultaneously … They are interactive, most likely in ways we have hardly begun to think about.
>
> *Wicked problems* are ill-defined, ambiguous and associated with strong moral, political and professional issues. Since they are strongly stakeholder dependent, there is often little consensus about what the problem is, let alone how to resolve it. Furthermore, wicked problems won't keep still: they are sets of complex, interacting issues evolving in a dynamic social context. Often, new forms of wicked problems emerge as a result of trying to understand and solve one of them. Wicked problems have been succinctly characterised as 'complex problems that change when you apply a solution. (Tanter 2009 on line)

Horn and Weber (2007: 29) adapt earlier formulations of criteria for wicked problems to develop the features of *social messes*: 'composed of inter-related dilemmas, issues, and other problems at multiple levels of society, economy, and governance'. There is no unique 'correct' view of the problem:

> *Social messes* are very complex, ambiguous, highly constrained, seen differently from different ideologies and worldviews, and contain numerous value conflicts … In time, the state of the systems that comprise a given social mess will change, in part because of the actions taken by stakeholders and in part because everything changes. Change is integral for interconnected complex systems that comprise social messes. (Horn and Weber 2007: 26, 29)

Dependency on petroleum as a finite resource leading to future depletion, is considered to have most of these characteristics to identify it as both a *global wicked problem* and a *social mess.* The resolution of the issues at all scales of urban development and city functioning at all levels of government (and internationally) are intractable propositions for many reasons, including control by global corporations, oil exporting countries and international cartels[12]. Some of the dimensions of the oil depletion problem are introduced in the following rather lengthy quotations that put oil dependency into stark perspective, if contemporary society is to transform successfully to a post oil economy. Peter Goodchild (2010) in his paper *The Imminent Collapse of Industrial Society* contends:

> Most schemes for a post-oil technology are based on the misconception that there will be an infrastructure, similar to that of the present day, which could support such future gadgetry. Modern equipment, however, is dependent on specific methods of manufacture, transportation, maintenance, and repair. In less abstract terms, this means machinery, motorized vehicles, and service depots or shops, all of which are generally run by fossil fuels. (Goodchild 2010: 6)

Norman Church (2006) adds another aspect to the technical debate about energy replacement by renewable sources, with which this thesis does not completely agree, as one renewable source could support another, but nevertheless accepts as an issue:

> On top of this we must remember that the energy budget must always be positive and output must exceed input. Too much tends to be expected of renewable energy generators today, because the contribution of fossil fuels to the input side is poorly understood. … [Renewable energy] input must also include, proportionately, mining and processing the raw materials and building the machines that do the work, as well as supporting their human operators. … The problem is that all the technology upon which we have come to depend requires a complete and sophisticated infrastructure to produce and maintain it, and that infrastructure is based on fossil fuels. (Church 2006: 1, 5)

These considerations are relevant to development of the contemporary built environment, as it depends so much upon inter-related imported materials and components; efficient energy sources; sophisticated manufacturing; and complex inter-modal transport technologies. However, the assertions need to be analysed. The complex interdependencies are considered a difficult field worthy of a separate PhD study, but could be approached in a general way by life cycle analysis. Part 2 of the thesis research investigates these issues in relation to constructing the built environment. Nevertheless, the technological complexities support the case for oil dependency and depletion being regarded as a wicked problem of global scale.

The adaptation to oil depletion is further complicated by the interaction of climate change mitigation/adaptation strategies and energy transition lead times. These issues are addressed in section 3.2. The global response to future oil vulnerability is made more urgent because of the lead time. Fatih Birol, the International Energy Agency Chief Economist (Newby 2011), concedes that 'governments should have started ten years ago' to find and develop the energy equivalent of four new Saudi Arabian oil

[12] Since the completion of this thesis research, the 2014-16 global oil price manipulation threatening the financial viability of USA tight oil fracking operations gives support to these assertions. The so-called oil glut is analysed to be mainly within USA for technical and geo-political reasons (ASPO 2016a).

fields.[13] A study of peak oil implications (Hirsch et al. 2007) also strongly suggests a lead time of 10 years is necessary prior to the peak period to make an orderly transition away from oil dependency toward alternative energy sources (see also section 3.2.4). However, the market driven transition would be buffered by substituting natural and coal seam gas; and by government policies to mandate prioritising oil and gas usage, while infrastructure for renewable energy for stationary and mobile applications is fully developed and scaled up in production to meet global demand (Droege 2006; Wilson & Burgh 2008; Brown 2009; Rubin 2009). The need for international cooperation and intervention highlights the wicked characteristics with great potential for global winners and losers. In a parallel to the global wicked problem of climate change, Lester Brown observes: 'no government wants to concede too much compared with other governments, the negotiated goals for cutting carbon emissions will almost certainly be minimalist, not remotely approaching the bold cuts that are needed' (Brown 2009: xii). Successive United Nations climate change conferences are testimony to the difficulty in gaining international support for action (United Nations FCCC 2012)[14].

The global wicked nature of both oil depletion and climate change is considered to be highly relevant to the strategic planning of urban areas in relation to management of uncertainty. An unpublished PhD thesis by John Abbott (2010) considers uncertainty in metropolitan planning of South East Queensland and Greater Vancouver. Issues of oil constraints and climate change would be viewed as external and causal uncertainties affecting the alternative possible future states of a region. These uncertainties are likely to lead to avoidance of decision making by governments due to political unpopularity, which reinforces the view that oil constraints are difficult to envision in planning terms.

This uncertainty was investigated by researchers in the Queensland Griffith University Urban Research Program, highlighting suburban oil fuel vulnerability (Dodson and Sipe 2008a, 2008c). The study draws on research evaluating the effects of rising fuel prices and higher interest rates, using a model called *vulnerability assessment for mortgage, petrol and inflation risks and expenditure* (VAMPIRE). The VAMPIRE map for Gold Coast is at **Figure 3.1** with reddish coloured suburbs shown as more vulnerable. The research examines some ways to 'oil proof' Australian cities by looking for petrol alternatives, urban consolidation and public transportation (2008a: 72). The alternative fuels review shows 'there are serious doubts about the ability of such fuel sources to replace petroleum at the same economic or environ-mental cost'. Hence Dodson and Sipe adopt a conservative view about the likelihood of car fuel being able to change to substitutes on a large scale in the medium term.

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13 Ironically tight oil was seen as the salvation needed to make USA a net oil exporter (EIA 2015: 132, 145); however, OPEC geo-politics intervened to dramatically cut prices and tight oil production (Meiners et al. 2016: 8). By 2016 the oil rig count was down by two-thirds from its peak (ASPO 2016b).

14 The 2015 UN Paris meeting (COP21) achieved a breakthrough commitment to action with 195 countries agreeing to 'pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels' spelling the end of the fossil fuel era (Climate Council 2015: 2). Oil depletion faces similar issues.

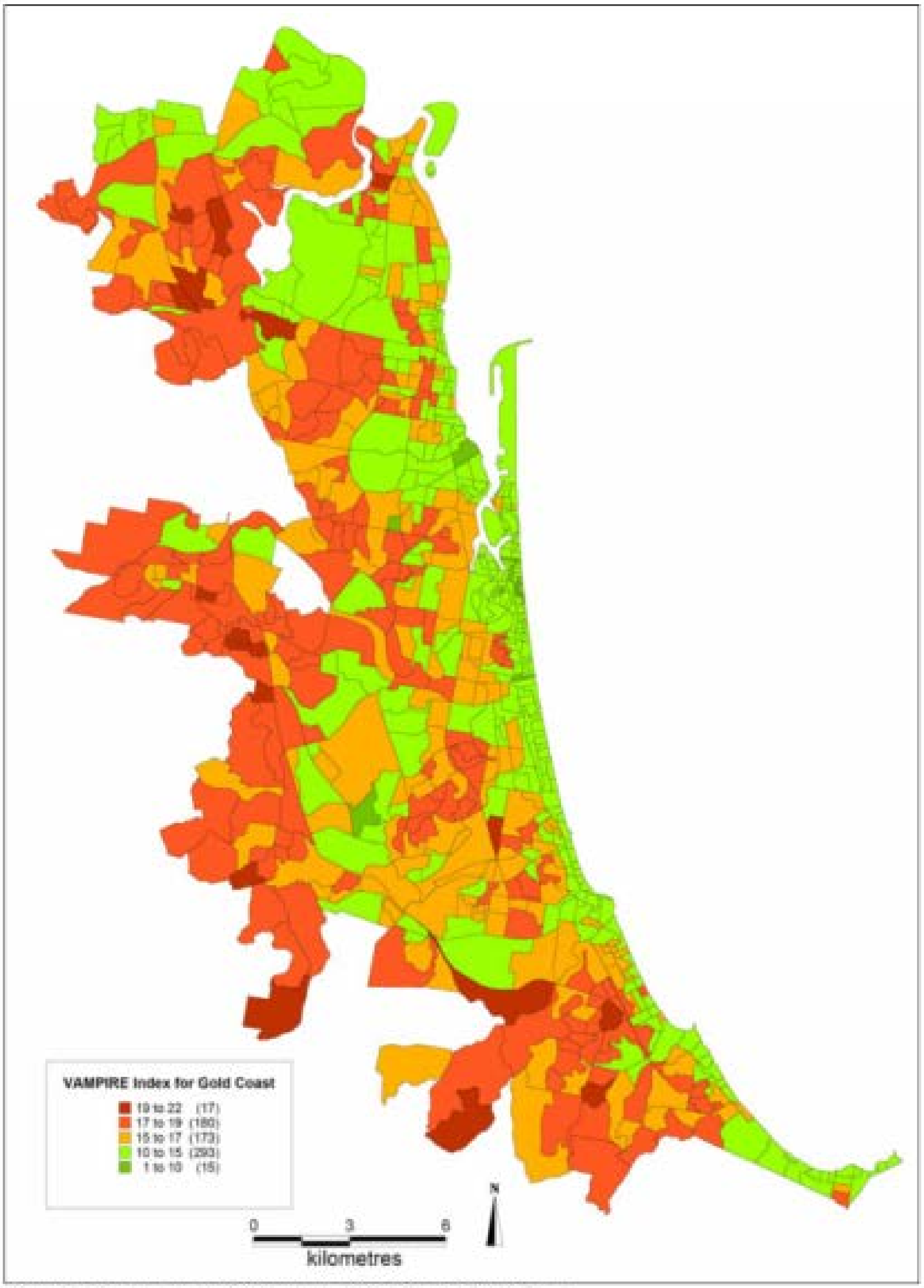

Figure 5 Mortgage and oil vulnerability in the Gold Coast

Figure 3.1: Oil and mortgage vulnerability—Gold Coast 2006

Source: Dodson and Sipe (2008a: 32) with permission

While this is a very useful empirical investigation, it tends to be misunderstood by governments so that oil depletion will be mainly a pricing issue restricting mobility, which could be resolved by urban consolidation and public transportation. Such a view reinforces the uncertainty issue in seeking simplistic solutions, rather than adapting to an oil-constrained future (e.g. Queensland Government 2009c; Australian Government Department of Infrastructure & Transport 2010a).

Just as this thesis research was nearing completion, the International Energy Agency (IEA) released its World Energy Outlook 2013 report. The summary report notes that '[m]any of the long-held tenets of the energy sector are being rewritten. Major importers are becoming exporters, while countries long-defined as major energy exporters are also becoming leading centres of global demand growth. … The rise of unconventional oil and gas and of renewables is transforming our understanding of the distribution of the world's energy resources' (IEA 2013a: 1). This statement highlights the complex uncertainties relevant to oil supply as a global wicked problem and to this research.

3.1.2 Global oil production and decline

In contrast to the previous century, the twenty-first century could be known as the era when the descent into a "long emergency" takes place (Kunstler 2005; Greer 2008), as a peak in the global supply of oil occurs in the early decade(s). Oil production rates will level off and then decline gradually as oil demand outstrips the discovery and exploitation of new oil sources. In fact Heinberg (2007) makes an eloquent case for 'peak everything', of which oil is only one, though a very important component, of several types of resource depletion, including water (which is essential in huge volumes for hydraulic fracturing ['fracking'] of shale and coal seams to extract oil and gas). The Association for the Study of Peak Oil and Gas (ASPO) (2002: 266) estimates that by 2000, as much as 1.75 trillion barrels of conventional oil had been discovered, out of an estimated world ultimate retrievable endowment of two trillion barrels. More recently the Oil Depletion Analysis Centre in London (ODAC 2012) cites '65 published studies by oil companies, geologists, government analysts and consultants over the past 50 years [that] have produced remarkably consistent estimates'. The overwhelming majority of these studies 'put the world's original endowment of recoverable oil at no more than about 2.4 trillion barrels; the average estimate is 2 trillion barrels'. More recent research by ASPO confirms their earlier results (ASPO 2013).

However, Leggett (2005: 25) notes that other oil industry and agency observers suggest two trillion barrels are *still* to be exploited. This is particularly relevant to industry predictions about USA tight oil and gas discussed below. Exploitation of tight oil in USA early in this century has confused the debate about the conventional oil production peak by comparing production from unconventional sources: e.g. tar sands deep oil, Arctic oil, natural gas liquids. The US National Petroleum Council (NPC)—an oil and natural gas advisory committee to the US Secretary of Energy—claims the endowment is 13-15 trillion barrels, but 'only a fraction of these estimated volumes can be produced' (National Petroleum Council 2007:17). The US Energy Information Administration (EIA) Annual Energy Outlook makes short–to-long term estimates out to 25 years about the prospects for oil supply and demand in USA. The 2012 report acknowledges that a high level of uncertainty defies accurate forecasts, because the conflicting views about the endowment of tight oil and gas (and high initial decline rates in each well) could vary estimates by 50 per cent more or less than the reference case:

> Estimated ultimate recovery [(EUR)] per well is a key component in estimates of both technically recoverable resources and economically recoverable resources of tight oil and shale gas. The EUR for future wells is highly uncertain, depending on the application of new and/or improved technologies as well as the geology of the formation where the wells will be drilled (US EIA 2012a: 59).

Adding to the uncertainty of global oil reserves is the potential exploitation of the Arctic Circle region that holds 'an estimated 13% (90 billion barrels) of the world's undiscovered conventional oil resources and 30% of its undiscovered conventional natural gas resources', according to the U.S. Geological Survey (US EIA 2012b). There are many geo-political, technological, production costs and environmental obstacles to overcome to make it feasible, although drilling is being undertaken as at 2013. However, whatever estimates of global oil sources are accepted for future energy reserves, the world has a limited fossil fuel endowment and a transition to other forms of energy is critical for both the energy security and global warming aspects. A successful transition depends upon many factors, but an early start geared around the conventional peak oil and gas plateaus would take into account the lead times needed for policy and strategy development.

Peak oil plateau

The peak oil plateau can only truly be recognised in hindsight, just as Hubbert's peak was confirmed many years after the USA production peaked in 1970 (ASPO 2005). This is partly because inadequate and politically biased reserves data reporting from around the world distorts the peak production timing estimates. ASPO considers it important to be aware of the timing of the peak, because mitigation and adaptation strategies need to be in place and implemented in sufficient time, so as not to exacerbate the pricing and supply problems (Aleklett et al. 2008). While the mid 2008 oil price spike, reaching US$147 a barrel (Rubin 2009: 17), was a foretaste of the future oil depletion scenario, the subsequent dramatic fall in wholesale oil prices to below US$40 a barrel lulled the world back into the delusion of business as usual with a never ending supply[15]. There have been several contested models for the timing of such a plateau in global oil production, but there is an agreed view about increasing global oil demand that would test the peak timing if production failed to meet demand (Rubin 2009: 17). In a September 2008 presentation, the NPC modified its stance on peaking of oil in a chart at **Figure 3.2** that indicates a global decline in existing conventional oil production capacity from 2007 at a rate of 4-7% per annum and the reliance on new capacity and unconventional sources to meet forecast demand (NPC 2008).

[15] The fall in oil prices was repeated after completion of the thesis research during 2014-15, thus reinforcing this opinion and producing what was falsely called an oil glut (ASPO 2016a).

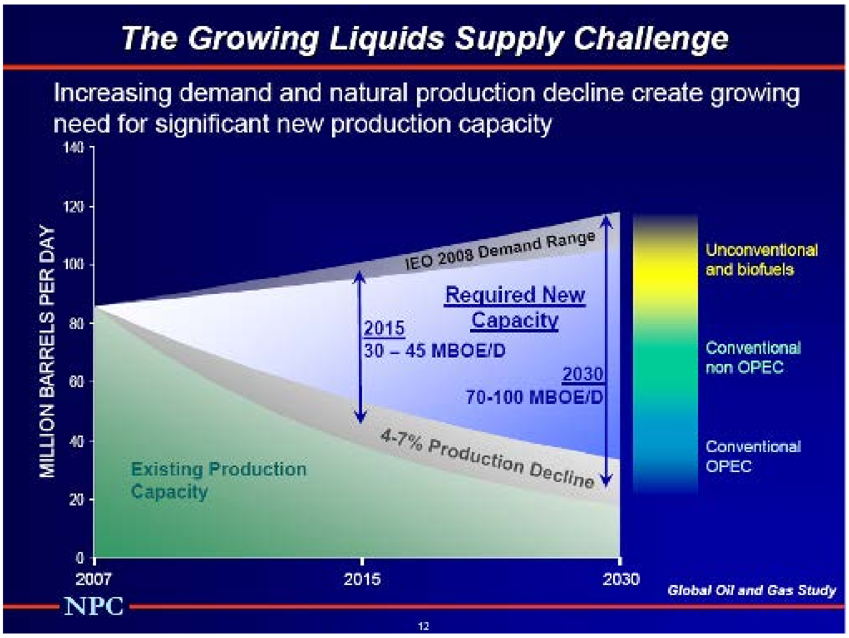

Figure 3.2: US National Petroleum Council 2008—Liquid fuel supply challenge

Source: An update presentation to National Petroleum Council (NPC 2008: slide 14)

By mid-2009 there was an emerging consensus of a narrowing range of the period of the peak oil plateau between 2008 and 2020. Some oil industry observers considered the peak plateau was reached right on schedule in the 2008–2010 period. Writing in the ASPO Newsletter No 97 January 2009 (ASPO 2009), ASPO founder and eminent oil geologist Colin Campbell stated 'The Depletion Model has indicated that the overall summit of all types of [oil] production will be passed in 2008, and it begins to look as if the mid-year surge [price in 2008] may indeed confirm this assessment.' The International Energy Agency in its World Energy Outlook 2010 summary report (IEA 2010: 6) finally acknowledged that global *conventional* crude oil output had peaked back in 2006 at 70 million barrels per day (mb/d), but noted *unconventional* sources were growing strongly to maintain a steady total oil output of 86 mb/d. The world oil production forecast under the new policies scenario is at **Figure 3.3**, showing the conventional crude oil plateau and depletion rate. The light blue wedge of oil fields yet to be found is expected to bridge the gap under the scenario to meet global energy demand, increasing by 40% between 2009 and 2035 (c.f. a similar wedge in Figure 3.6). The yellow band indicates oil sands, tight and deep oil. These wedges of new capacity and sources parallel the NPC scenarios in Figure 3.2. However, the underlying dark blue colour highlights the steadily declining global supply of conventional oil.[16]

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16 The IEA World Energy Outlook (2015: 132-145) commentary on oil production prospects suggests that:

> After 2020, even though oil prices reach levels that allow upstream investment to pick up again, the collective output of non-OPEC countries does not resume growth, particularly once production from the United States – so important in the market over the decade to 2020 – reaches a plateau and then enters a gradual decline. As it does so, the United States yields, in the mid-2020s, the top spot in the global output ranking to Saudi Arabia … By 2040, conventional crude oil accounts for only 66% of total production, compared with 87% in 2000 (IEA 2015: 132-133).

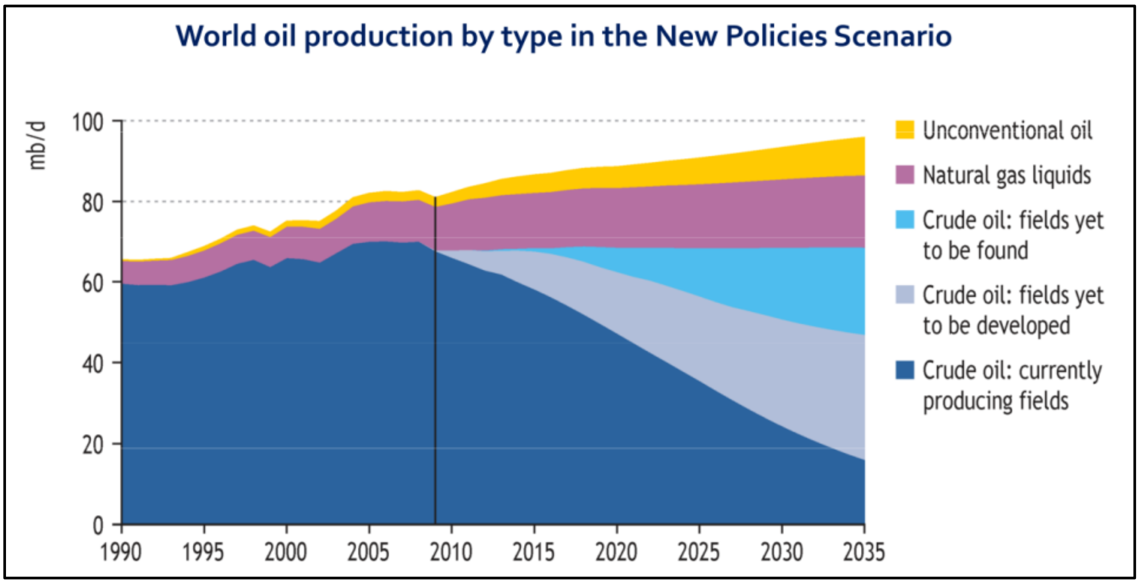


Figure 3.3: World energy outlook 2010 world oil production

Source: IEA 2010.

Unconventional oil and gas to the rescue

The unconventional and NGL sources are not directly equivalent to crude oil, because of much lower energy return on energy invested (EROEI) ratios for extraction and production (c.f. the law of diminishing returns). The EROEI for conventional crude oil in the 1930s was about 100:1. By 2010 it had dropped to less than 20:1. EROEI was much lower for shale oil, biofuels fuels such as corn based ethanol and tar sands oil that are in a range of 2-6:1 (Heinberg 2011: 119). There has been estimated a net energy cliff at about 5:1 so these alternative fuels are at or over the cliff to be viable in the long term; in the USA, tight oil in the Bakken North Dakota fields required a price of $85 to remain viable in 2012 (The Oil Drum 2012)[17]. This issue led the IEA to suggest that 'unconventional sources of oil are among the most expensive and will play a key role in setting future oil prices' (IEA 2010: 7).

The later IEA World Energy Outlook 2012 cautions that 'taking all new developments and policies into account, the world is still failing to put the global energy system onto a more sustainable path' (IEA 2012: 1). The report includes a graph of potential unconventional tight oil and gas production in the USA to support its case about new energy growth, reproduced at **Figure 3.4**. It shows increasing reliance on unconventional sources—particularly tight oil and gas—into the present century to counter a steady decline of conventional sources. It also indicates a reduction of conventional oil production to less than 50 per cent from 1980 levels as soon as 2015, with a growing dependence on gas sources over 50 per cent after 2015. Again, the text accompanying the graph does not register the differing EROEI ratios for unconventional sources, except by using an equivalent energy measure based on

[17] The impact of the price plunge to US$30 a barrel in late 2015 highlighted the fragility of the tight oil plays and saw both production declines and financial stress in the industry (ASPO 2016b).

barrels of oil—i.e. the input energy differences were disguised in the graph. The imported oil and renewable sources are also omitted. The IEA World Energy Outlook 2013 summary report acknowledges the significant potential of shale oil production to make the USA the world's largest oil producer in this decade (IEA 2013a: 4). However, it hints that after the 2020s, production will reduce, as indicated in Figure 3.4, partly because continuous drilling investment is required to offset rapid field-level declines.

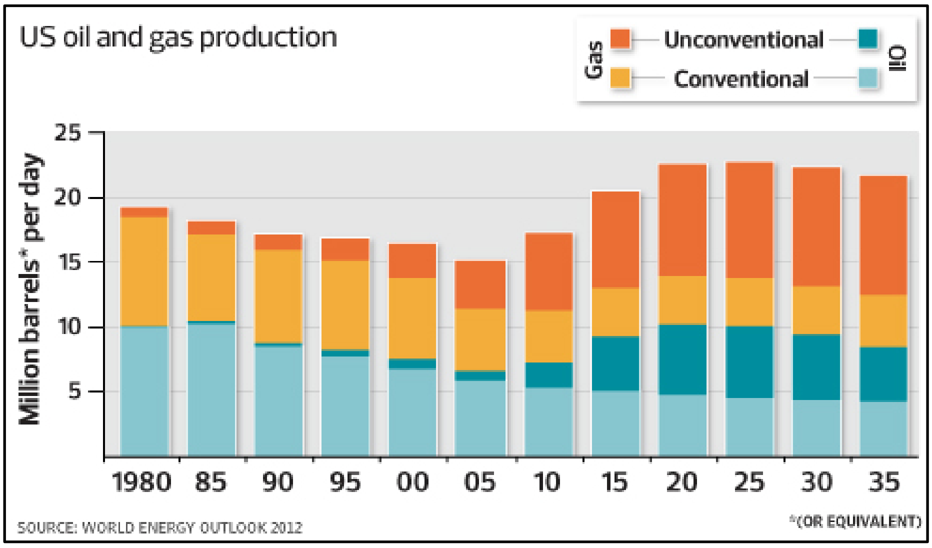


Figure 3.4: World energy outlook 2012 USA oil and gas production

Source: IEA (2012)

Declining oil supply

The energy transition is predicated upon a gradual decline in oil supply and an equal or better rate of change in renewables for static and motive energy technology. The IEA suggests that more than half of the 790 billion barrels required to meet global projections for demand to 2035 'is needed just to offset declining production' (IEA 2013b: 4). Despite the optimism in the USA about tight oil, even the smooth descent path in Figure 3.3 indicates the global conventional oil supply will be halved by 2035, which is within the current strategic planning horizon. The IEA World Energy Outlook 2013 confirms a 6 per cent decline rate in existing conventional oil fields and a fall in output by over 40 million barrels per day (mb/d) by 2035, which accords with Figure 3.3.

This has to be compared to a revised forecast global daily output (from all sources) of 101 mb/d in 2035, with oil demand for transport reaching 59 mb/d and for petrochemicals making up 14 mb/d (IEA 2013b: 4). Renewables will 'account for nearly half the increase in global power generation to 2035'; of which wind and solar photovoltaics will be 45 per cent, according to the IEA predictions (2013b: 5). However, the consequent slide down the back side of the peak, shown in Figures 3.2 and 3.3, would be more likely to resemble a rocky road than the steady 6 per cent decline, but could be a series of episodic events with partial recovery, and/or sudden drops to lower levels of export from oil producing nations. Oil exporting countries are expected to withhold stocks from export in order to provide longer term security for their domestic needs by extending the life of their oilfields, or to manipulate the international oil market, causing price spikes as supply drops (Rubin 2009: 205).

The conclusion is that, on the basis of the IEA forecasts, the global conventional oil supply will be halved by 2035, without massive new oil finds on a scale that has not been seen since the 1980s—equivalent to four Saudi Arabias. Even the optimistic US forecasts in Figure 3.4 rely on tight oil to make up over 5 mb/d. Tight oil production in the USA is concentrated in North Dakota (Bakken) and Texas (Eagle Ford) plays. These and other plays are set to maintain output at the projected plateau level of around 4.3 mb/d between 2025 and 2030, with a slight drop by 2035. Maintaining that level requires drilling 1000s of new wells per year (WEO 2013c:475-76). On a global scale, however, the IEA (2012: 82) forecasts total energy demand under a new policies scenario continually rising to over 4,000 million tonnes of oil equivalent energy. The graph reproduced in **Figure 3.5** shows the highest rate from 2010 to about 2017, with China and India accounting for 50 per cent of the total growth to 2035.

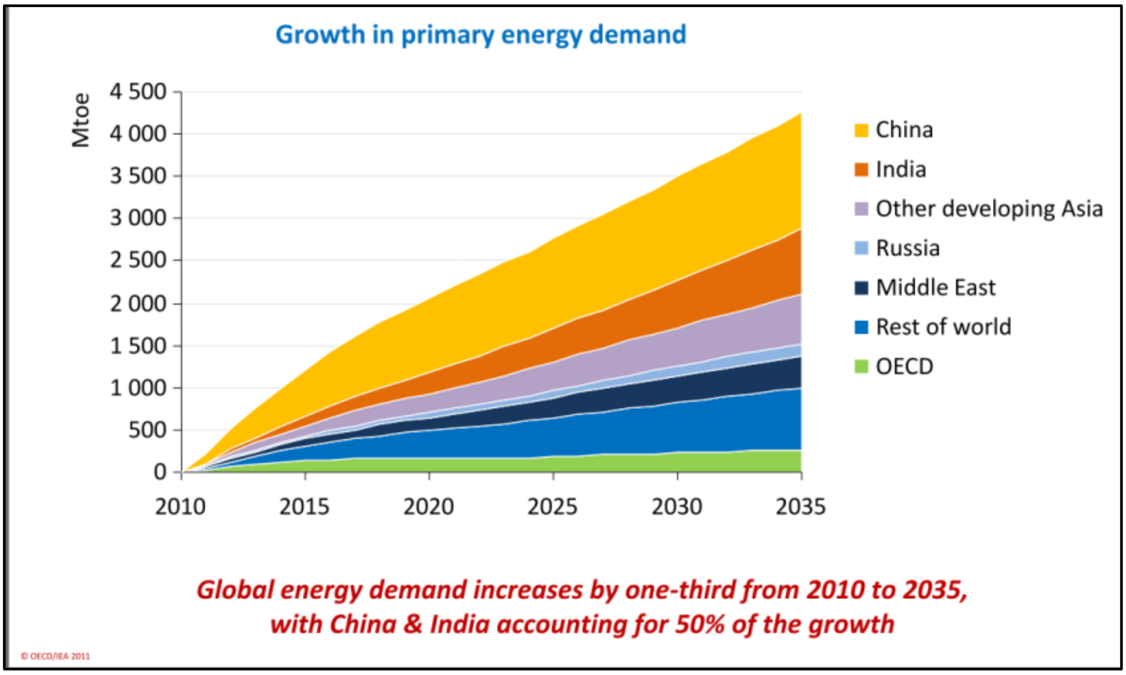


Figure 3.5: World energy demand forecast

Source: IEA World Energy Outlook (IEA 2012)

3.1.3 Oil depletion implications research

Since the early 2000's, many researchers have written about the wider implications of oil depletion to raise awareness and advocate changes in the policy and practice of sustainable development. This section describes and evaluates works in the non-planning and planning related literature to outline the key messages relevant to the research problem and the working propositions of research question 1 of this thesis.

Oil depletion awareness raising in non-planning literature

Many, if not most, of the most influential published works about oil depletion and its effects have not been authored by planners, but by social/environmental commentators (e.g. Kunstler 2005, Brown 2006, Doucet 2007, Heinberg 2007 and Girardet 2008); ecologists (Greer, 2008; Hopkins, 2008); geologists and engineers (e.g. Campbell, 2002; Leggett, 2005; Hirsch 2007; Gilbert & Perl 2010; Aftabuzzaman & Mazloumi 2011); economists (Rubin 2009) and politicians (Gore, 2006). The conclusions inferred from and supported by several commentators are that the petroleum vulnerability effects should be set in the bigger 'wicked problem' picture of global crises, resource depletion, water supply shortages, food security, political upheaval and of course climate change. Failure to adapt to oil depletion is considered by some of these commentators to have the potential to cause a catastrophic breakdown of urban and particularly suburban economic livelihoods and social lifestyles in developed countries, which are inextricably dependent upon the petroleum economy.

Jeff Rubin (2009) approaches the issue of peak oil and its implications for the future of modern civilisation from an interesting perspective—that of an oil expert economist, who back in 2000 predicted the soaring oil prices. He considers the oil price spike in 2008 is a contributing cause, rather than an effect, of the global financial crisis and *great recession* (2009: 18). The credit bubble needed low inflation, which relied on cheap energy. He also looks beyond the doom and gloom of oil depletion, to encourage the reader to grasp the opportunities for localisation (going local) and downsizing our bloated materialistic existence—transforming to a small new world. The interest for this research in Rubin's study of oil depletion in all its ramifications is its relevance to adapting cities and suburbs to an oil-constrained future. Rubin's insights in 2009 are regarded to be as valuable as Kunstler's ground breaking, sobering view back in 2005 of all the converging catastrophes. Rubin shares Kunstler's view that the future will look a lot like the past, in relying on more farmers and local food production. His views are also sympathetic to the transition towns movement, which is discussed in section 8.2.6. Rubin's expertise in evaluating the economic perspective is a counterbalance to the alternative fuel optimists. He contends peak oil could also mean peak gross domestic product, but it does not have to 'if we can de-link economic growth from oil.' (2009: 23). Rubin's plan 'B' is not optional, but a step toward the 'small new world' of Lester Brown's 'Plan B' (Brown 2009), which postulates detailed plans for stabilising climate and population, eradicating poverty, restoring the earth's damaged ecosystems, and a transition to cities designed for people.

The persuasive conclusions of the above commentators predict a fundamental paradigm shift from globalisation to localisation, and self-containment with reduced standards of living, which could affect the sustainability of the developed world cities. The urban forms and infrastructure supporting suburban lifestyles, employment and facilities might gradually become problematic, even in the post-modern knowledge economies. The oil constraint issues could affect all aspects of development, as well as food production (Pfeiffer 2004), international trade and travel—particularly tourism. The literature research finds that current trends towards 'housing obesity' have already been reversed by the changing economic environment—more so than by changing demographics—towards smaller and possibly more affordable units in community living, such as co-housing, which is discussed in section 8.2.1. This view is supported by Newman and Jennings (2008: 193) and Riddell (2004: 231), as well as the Queensland Urban Land Development Authority (2012) in its land development guides.

Oil depletion awareness raising in land use planning literature

Until recently, land use (spatial) planning literature largely has failed to address the consequences of an imminent plateau of peak oil and subsequent oil supply depletion and energy constraints, as they may impact on future urban development in the Australian and wider global context. The notable exception is the often cited studies by Newman and Kenworthy (1999). The literature review of publications in the 1990s — early to mid-2000s on land use planning, sustainable development and related subjects, searching indexes for key words peak oil, oil depletion, petroleum and energy resources and similar words revealed no such references. Since the mid-2000s planning researchers have linked the future of cities to peak oil and oil depletion, including Chiras and Wann (2003), Newman et al. (2003, 2008, 2009), Droege (2006), Lerch (2007), Greer (2008), Dodson and Sipe (2008c), Coyle (2011). This work has also linked to extensive research on adaptation of building design and energy conservation in cities as a response to climate change (e.g. Lowe 2005; Droege 2006; CSIRO 2006, 2008; Girardet 2008). Yet in 2012, the Royal Town Planning Institute released a critical discussion paper *Peak Oil: the implications for planning policy* to document findings of a study on the implications for spatial planning. It reported that the UK Government National Planning Framework is 'silent specifically on issues relating to the implications of Peak Oil'. Transport policy had also been reviewed at the national level and 'remains resolutely silent on the issue' (RTPI 2012: 17-18). This policy weakness in a country so closely aligned to traditional Australian planning philosophy is a warning for current planning studies and policies not to fall into the same trap.

Searches of PhD and Master Degree theses revealed only a few relevant oil-related planning topics have been reported up to 2012[18]. For example, an Australian Master's Degree thesis by Cathrina Yanuaria investigated two benchmark suburbs—Joondalup and Woodlake—in Perth Western Australia in relation to the transport elements of sustainability (Yanuaria 2004). She found that whilst Woodlake performed better than the older Joondalup in energy consumed and greenhouse gases emitted, the future may be less sustainable. A technical evaluation by Fang Rong (2006) in her PhD on the impact of urban sprawl on US residential energy use demonstrated that residents in sprawling city areas consume more operational energy than those in compact areas.

[18] A search since completion of this research revealed one relevant thesis (http://trove.nla.gov.au/), which is PhD research on development oriented transit and Gold Coast light rail (Mepham 2013).

Relevant Australian oil-related planning policy research

Added to the body of academic literature are a growing number of Australian policy research papers and planning strategies, such as the three growth studies discussed in chapter 2. The Griffith University Urban Research Program has published several papers that address oil-related planning issues, including the VAMPIRE study cited in section 3.1.1 (Dodson & Sipe 2008a, 2008c). The Curtin University of Technology Sustainability Policy Institute is also active in urban policy research, including several studies by Peter Newman and others cited in this thesis. The Melbourne University based Grattan Institute, founded as a think tank in 2008, focuses on key policy areas including urban and energy issues. The Planning Institute of Australia first devoted a journal issue in December 2006 to articles on energy planning (Wright 2006) and peak oil (Taygfeld 2006). Taygfeld found that while the Queensland Government had established an Oil Vulnerability Task Force, there was considerable political reluctance among senior bureaucrats and politicians to acknowledge peak oil, causing policy inertia (2006: 17). The 2007 report of the task force was to be implemented as a strategy, but it had not been released prior to the change of government in March 2012 and was not reactivated by the new Campbell government (Wilson, B, pers. comm., 25 October 2012). The report is unlikely to be considered in the ongoing review of the SEQ Regional Plan. In contrast, some forward thinking local governments in SEQ including Moreton Bay (2009) and Sunshine Coast (2010) Regional Councils, and Redland City Council (2010) have published strategies, including specific references to peak oil and oil vulnerability, mainly in the climate change and liveability context. These studies were driven by staff with high awareness of peak oil and its implications for cities according to a council planner(Wight, W, pers. comm., 19 June 2010). Two similar peak oil strategies are the City of Stirling in Perth and City of Maribyrnong in Melbourne noted in section 2.4.1 and 2.4.2 respectively.

In May 2011 the Australian Government (2011) released a National Urban Policy based on research by the Major Cities Unit to meet the challenges of long term productivity, sustainability and liveability of the 18 major cities over 100,000 population. Neither the policy nor its supporting research papers addresses peak oil issues in detail, apart from reference to the VAMPIRE model, but does set objectives to improve climate change resilience and energy security, and reduce dependence on private vehicles. The policy cautions that 'simply infilling existing areas without improving the amenity for existing residents is problematic' and advocates housing close to jobs and public transport, in more compact mixed use development' (2011: 56). Sustainable development with energy efficiency objectives is geared mainly to reducing greenhouse emissions; hence the urban policy framework focuses on wider goals of less carbon-dependent ways of living (2011: 7). This discussion of the oil research leads to a review of the relationship with climate change in the next section.

3.2 Oil depletion and climate change

As noted in sections 1.1 and 3.1.1, an important consequence of oil combustion in all its forms and the resultant greenhouse gas emissions is its contribution to global warming and climate change, which is widely regarded as a key global wicked problem. This section addresses the relationship between oil consumption and climate change as twin global problems, particularly in the Australian policy context, and draws on recent reports that are relevant to this research.

3.2.1 Oil depletion and climate change relationship

In October 2008 on the verge of the 'great recession', eight leading UK companies launched a report, *The Oil Crunch: Securing the UK's energy future*, warning that a peak in cheap, easily available oil production was likely to hit by 2013, posing a grave risk to the UK and world economy. The group cautioned that while the government policy emphasis is on climate change responses, 'the Taskforce analysis is that peak oil is more of an immediate threat to the economy and people's lives than climate change' (Arup et al. 2008). The Taskforce updated the report in 2010 with allowances for the great recession, and US shale gas and its positive effect on CO_2 emissions. The report concludes the oil crunch could be delayed by at least two years to 2015 (Arup 2010: 26). In 2013 the new UK Government announced an oil and gas strategy to fully exploit the existing North Sea resources, as a buffer while pursuing a long term goal to decarbonise the economy to achieve an 80 per cent reduction in CO_2 emissions (UK Government 2013).

In Australia the Garnaut Climate Change Review makes recommendations for urgent action to reduce carbon emissions (Garnaut 2008). The report includes the issues of energy security within that context. It recognises transport, land-use and buildings are major contributors of greenhouse gas emissions, and that cities are major centres for energy demand, requiring large quantities of energy in both construction and operation. Implementation of climate change mitigation planning principles should embrace broader sustainable development principles and energy transition to a low carbon economy. This includes consideration of energy supply infrastructure, embodied energy and operational energy demand from buildings, and urban infrastructure. Cities should achieve the form, density and spatial pattern of urban development and associated infrastructure that reduce greenhouse emissions.

A 2011 review of the report (Garnaut 2011) takes into account the findings of more recent climate change research and global conferences, and relevant considerations of the global financial crisis (the great recession). The update accepts the 2010 IEA forecast of only a slight decrease in global oil supply from 31.5 per cent to 28.5 per cent to 2030, and concedes that changes in fuel mix rely on gradual replacement of infrastructure and fleet which is problematic with a long lead time (Garnaut 2011: 24).

In contrast, an earlier study by Droege (2006) makes a stronger link between climate change and peak oil, urging that preparing cities and regions to:

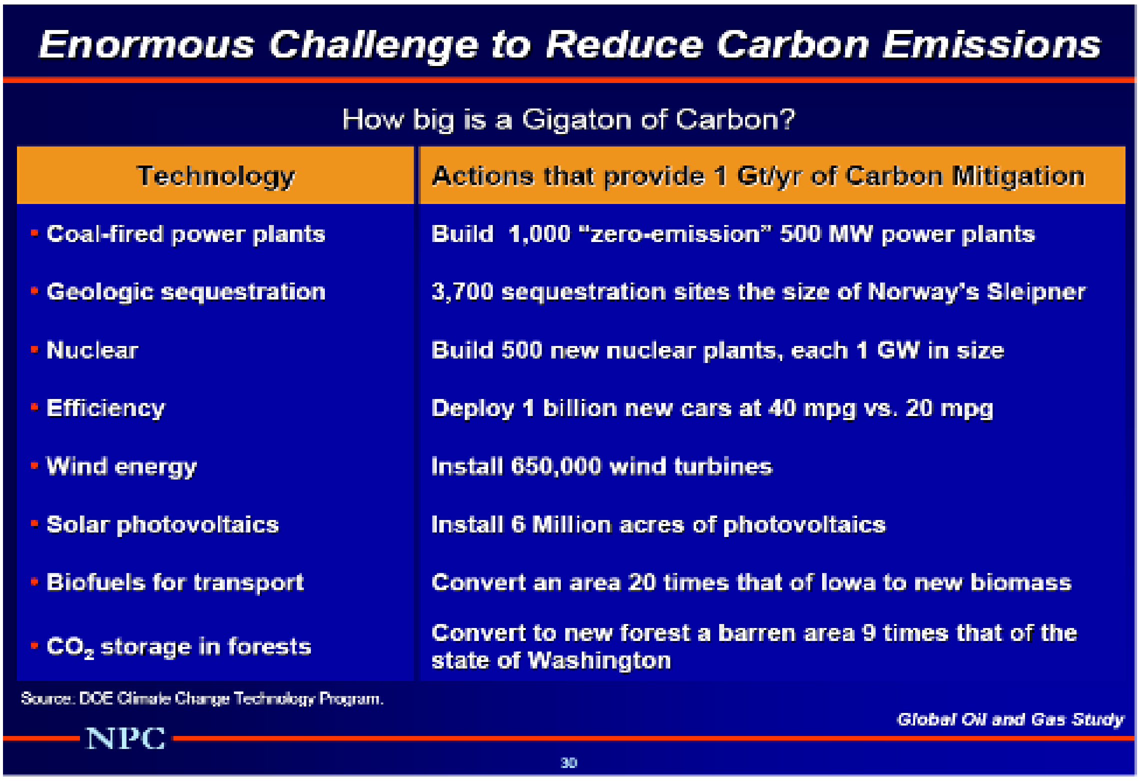
> strengthen regional and urban economic and energy autonomy, are the most sensible strategies to prepare for both Peak Oil and climate change ... Of these two, Peak Oil poses decidedly more imminent risks to cities and human settlement and, some argue, may well serve to help mitigate climate change. (Droege 2006: 60-61)

The complexities of the economic, social and environmental consequences of oil depletion extend well beyond the context of urban development, noted in the Garnaut review into every facet of modern society and technology. Newman and Jennings (2008: 37) contend that current trends in urban development are not sustainable under these circumstances:

> The two problems are clearly linked — if cities try to move from oil to 'dirty fuels' like oil shale, tar sands, or coal to liquids, this will be much worse in greenhouse terms. Saving oil on the other hand will be a major contributor to reducing greenhouse [effects]. (Newman & Jennings 2008: 37)

Oil dependency and efforts to maintain global oil supply have already been addressed as an emerging global problem. Hence the interlinked issues of oil supply depletion and climate change are arguably two of the key global problems of this century (along with water and food security). The Australian Senate *Inquiry into Australia's future oil supply and alternative transport fuels* (Australian Senate 2007) was released during the period of rapidly rising oil prices, but prior to the great recession. The report was prompted by the question of 'peak oil' and presented a detailed study into the peaking of global oil supply and the demand implications for Australia. The peak oil timing uncertainty, demand inelasticity causing high volatility in prices calls for prudent action to reduce oil dependency and mitigate greenhouse emissions. Alternative fuels all have energy cost and emissions penalties (Australian Senate 2007: xii-xiii). These views are echoed in a similar study: *Queensland's Vulnerability to Rising Oil Prices Taskforce Report* (Queensland Parliament 2007); and *Oil Vulnerability Strategy/Action Plan for Queensland research paper* (Waller 2008). The Waller paper overviews a range of critical issues and poses broad principles for mitigation strategies. One of the key messages is that the Queensland economy is protected by its large coal, coal seam gas and natural gas resource endowments, which 'provide a natural hedge against the oil price outlook' (Waller 2008: 10). This 'soft' message overlooks the obvious reliance on future clean coal technology to lower CO_2 gas emissions. It also seeks to perpetuate the exploitation of fossil fuels.

The IEA estimates that under its New Policies scenario, the global energy sector will generate 37.2 giga tonnes (Gt) of CO_2 (equivalent) in 2035, with a 20 per cent increase from 2013 (IEA 2013c: 1). The effort involved to lower CO_2 emissions is indicated in a US National Petroleum Council 2008 presentation on energy futures. It includes a comparison of actions shown in **Figure 3.6** to provide the equivalent of one (US) Gigaton per annum of carbon mitigation, including renewable power generation, transport energy efficiency and carbon sequestration (NPC 2008: slide 30). The examples represent a huge effort (currently all depending on the oil economy) needed in developing and in many developing countries, if a global response is to restrict average temperature rise to 2˚C in the most optimistic IPCC scenarios. Unfortunately the IEA considers that on current energy forecasts the world is on a trajectory for at least a 3.6 ˚C rise[19]. Of course there are many combinations of mitigating actions that could be undertaken; however Figure 3.6 indicates the scale of the effort required. The next section compares oil and climate change mitigation and adaptation action concepts.


Enormous Challenge to Reduce Carbon Emissions

How big is a Gigaton of Carbon?

Technology	Actions that provide 1 Gt/yr of Carbon Mitigation
Coal-fired power plants	Build 1,000 "zero-emission" 500 MW power plants
Geologic sequestration	3,700 sequestration sites the size of Norway's Sleipner
Nuclear	Build 500 new nuclear plants, each 1 GW in size
Efficiency	Deploy 1 billion new cars at 40 mpg vs. 20 mpg
Wind energy	Install 650,000 wind turbines
Solar photovoltaics	Install 6 Million acres of photovoltaics
Biofuels for transport	Convert an area 20 times that of Iowa to new biomass
CO_2 storage in forests	Convert to new forest a barren area 9 times that of the state of Washington

Source: DOE Climate Change Technology Program.

Global Oil and Gas Study

NPC

30

Figure 3.6: US National Petroleum Council 2008 — carbon offset comparisons

Source: National Petroleum Council (2008: slide 30)

3.2.2 Oil and global warming mitigation and adaptation comparison

The terminology used in climate change research and policy makes a distinction between mitigation and adaptation and is fairly well understood [e.g., IPCC 2007; Garnaut 2008]. This terminology is also loosely used in literature and policies dealing with oil depletion, mainly identified as mitigation strategies (e.g. IEA 2010; RTPI 2012). This can be confusing because actions to mitigate oil depletion are applied both to conserving supply and finding alternatives. However, the terminology is a reasonable

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19 The IEA 2015 outlook welcomes COP21 intentions, but is pessimistic that it will be sufficient without rapid shifts in end-use sectors, including oil as a transport fuel, to reverse the trend of rising CO_2 emissions (IEA 2015: 27). This is reinforced in COP21 agreement Clause 17 that 'Notes with concern that the estimated aggregate greenhouse gas emission levels in 2025 and 2030 resulting from the intended nationally determined contributions do not fall within least-cost 2 ˚C scenarios (2015: 3).

analogy to analyse peak oil response actions, but notes that it needs to be modified for oil. The terms used for climate change are defined as:

Mitigation: Actions that reduce the impact of human activity on the sources of greenhouse gases or enhance their sinks, aimed at reducing the extent of global warming [i.e. to retard rising global average temperatures].

Adaptation: The process of adjustment to climate changes that will occur despite efforts to reduce greenhouse gas emissions. Adaptation planning actions can adjust natural or human systems in response to climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. These actions will contribute to increasing resilience of human settlements to [the progression of] climate change.

Adaptive capacity: The ability of social, economic, environmental, institutional and the political systems to adjust to change, moderate potential damage, take advantage of opportunities, and cope with the consequences.

(Source: IPCC 2007: 871)

There is also a category of dual-purpose (cross-cutting) actions that have aspects of both mitigation and adaptation; or that are complex and difficult to allocate. Transformation of the above terminology to apply to future oil supply constraints in the context of urban development could be defined in the following proposed terms:

Oil demand mitigation:

Conserving oil supply and reducing price vulnerability

Mitigation actions reduce the impact of land development and building construction activities on global oil demand, aimed at prolonging oilfield production and reducing the extent of vulnerability to oil supply and pricing.

Oil supply adaptation:

Urban development less dependent on oil supply and adaptive living to increase resilience

Adaptation is the process of adjustment to globally reducing oil supply that will occur despite efforts to reduce oil demand. Adaptive actions adjust land development and building construction activities in response to oil supply shortages or their secondary effects, which moderates the extent of supply vulnerability and increases resilience. It also includes lifestyle changes toward adaptive living.

Adaptive capacity:

Adjusting systems to be resilient to decreasing oil supply and higher pricing structure

Adaptive capacity is the ability of social, economic, environmental, political, and institutional systems to adjust to changes in oil supply and pricing vulnerability, moderate potential damage, to take advantage of opportunities, and cope with the consequences of reducing oil supply. These actions will contribute to increasing resilience of human settlements to oil supply vulnerability and depletion.

3.2.3 Mitigation and adaptation actions—a case study

In accordance with the proposed definitions, if an oil-related material can be produced, or an oil-related process can be undertaken, in a more fuel/energy efficient way, the issue becomes one of mitigating the vulnerability. If a suitable substitute material or alternative process is available, the issue is more one of adapting to the vulnerability. As in climate change actions, however, these notional distinctions become blurred in relation to oil vulnerability; because actions to mitigate (use less oil) can also be applied to adaptation (adopt the use of alternatives). This is in contrast to climate change where increase in greenhouse gas emissions can result from several unrelated causes and lead to a range of consequences. These vary from global warming and more extreme weather events to sea level rise and ocean acidity (IPCC 2007). Some effects may be both beneficial and adverse, such as the geographic shift in temperate climatic zones. These are multivariate consequences. There is a large body of documented evidence dealing separately with climate change mitigation and adaptation aspects (e.g. Garnaut 2008b, IPCC 2007a, IEA 2013a). However, there is not a similar body of research and policy in relation to oil policy that deals separately with mitigation and adaptation strategies in a consistent analytical manner.

A search of the literature failed to reveal any research comparing oil and climate change mitigation and adaptation. Fortunately a book released at the 2010 World Oil Conference in Washington DC provides a case study, which follows a 2007 report on peak oil implications by the same authors (Hirsch et al. 2010). The study addresses oil mitigation issues in two ways using administrative measures and physical options. The primary objective is to address the argument that 'an uninterrupted supply of moderately priced oil is essential to world economic wellbeing, let alone growth' (2010: 84). The thrust of this strategy appears to attempt to mitigate depletion to maintain a business as usual approach to the use of oil in the American context. The investigation into the 'impending world energy mess' is summarised in three aspects:

a. the impending decline of world oil production, which the world has yet to fully comprehend, let alone prepare for
b. the intoxication with renewable energy, which is incapable of providing the world with large amounts of liquid fuels or electric power at costs comparable to alternatives
c. climate change, the consideration of which has overshadowed a multitude of energy decisions in spite of the fact that there are large questions in the science. (Hirsch et al.2010: 231)

The authors conclude that even if all the suggested oil mitigation measures were implemented quickly, 'oil shortages will almost certainly grow more rapidly than our best mitigation efforts, and this implies significant world shortages before our mitigation efforts catch up and surpass world oil production declines' (2010: 233). This conclusion implies liquid fuel supply will somehow match future demand, albeit on a reduced scale from biomass, oil shales, tar sands, gas-to-liquid and algae sources

(2010: 145-172). The authors envisage transport fuels would be complemented by the conversion to natural gas and electrification of vehicles; and clean coal, gas and nuclear power generation, supplemented by solar and wind power. They take a pessimistic view about 'the concept of renewable energy with its promise of eternal energy from nature' (2010: 234) as being incapable of satisfying the overall energy needs of the USA.

No specific distinction is made between oil *mitigation* and *adaptation* measures. In a personal communication at the October 2010 ASPO World Oil Conference, the lead author Robert Hirsch reinforced this view by not holding an opinion about any relevance of a separation of these aspects, and tended to combine the two terms. Nevertheless, a closer examination is warranted to determine if some of the suggested 'mitigation' options are more related to 'adaptation', as described in the above proposed definitions, despite the lack of semantic separation. The Hirsch mitigation measures summarised below are tabulated in **Table 3.1**, indicating how closely they align with the proposed *mitigation* and *adaptation* definitions:

Administrative measures: These cover 'options that can be implemented by individuals, organizations and governments, either voluntarily or via mandates'. They include rationing of oil supplies, car-pooling and telecommuting [25: p.85].

Physical mitigation measures: These include deployment of more fuel efficient vehicles; more reliance on heavy oil and oil sands, gas to liquids, coal to liquids, and enhanced oil recovery technology [25: p.111]. A range of options are discussed for alternative fuels, electric vehicles and stationary power generation.

Table 3.1 uses a non-metric ordinal scale to demonstrate that most (9 out of 16) of Hirsch's proposed mitigation measures could also have varying relevance to adaptation measures. However, the options such as telecommuting, plug-in electric vehicles, hydrogen fuel cells, solar and wind power to be adaptive strategies to cope with less oil supply. Other options such as plug-in hybrid electric vehicles and natural gas (both for transport and stationary power) are considered to be slightly more aligned to mitigation. This is because they are both exploiting a finite fossil fuel to maintain a business as usual approach to transport and motorised machinery. Rationing of oil supplies is important to both aspects. The other relevant measures are more aligned to mitigating oil demand to conserve future supply.

The analogy between oil depletion and climate change actions suggests that the proposed set of definitions could (simplistically) be applied to categorise oil depletion measures. The table indicates that the 'XXX' (close fit) rated measures are considered in this thesis to most closely fit the proposed definitions, as effective policy actions or strategies. While the categorisation has a subjective aspect that is open to debate, it is based on the author's professional policy experience in climate change and peak oil research. Interestingly, the mitigation 'XXX' actions are a much closer fit for 11 of the 16 in the list. Adaptation actions are almost evenly spread: 'XX' (highly relevant) plus 'XXX' actions making up only half the total. There is also a close commonality in relevance between nine of the 16 mitigation and adaptation actions. The above analysis shows that mitigation actions dominate. It also appears to support a view that a notional separation is blurred by cross-cutting measures, as actions to mitigate (conserve oil supply) can also apply to adaptation (using alternatives).

Table 3.1: Comparison of Hirsch et al. measures with the mitigation—adaptation definitions proposed in this thesis

Mitigation options proposed by Hirsch et al. (2010)	Descriptive definitions proposed by Roger Brewster	
	Mitigation action	Adaptation action
Administrative measures:		
Pricing and allocation controls for rationing of oil supplies	XX	XX
Car-pooling	X	XX
Telecommuting	XX	XXX
Physical measures:		
More fuel efficient vehicles including: - hybrid electric vehicles - plug-in hybrid electric vehicles - plug-in electric vehicles	 XXX XXX XXX	 X XX XXX
More reliance on heavy oil & oil sands	XXº	–
Enhanced oil recovery	XXX	–
Coal to liquids	XXX	–
Alternative transport fuel options: - Natural gas - Gas from shale and coal seams - Biofuels - Hydrogen fuel cells	 XXX XXXº XXXº XX	 XX Xº Xº XXX
Solar power generation	XXX	XXX
Wind power generation	XXX	XXX
Nuclear power generation	XXX (subject to waste issues)	XXX (subject to waste issues)

Key: **–** Not relevant to land development and construction adaptive actions, including transport
X Relevant
XX Highly relevant
XXX Close fit to proposed definitions
º Not preferred because of environmental, food security, or greenhouse gas impacts

It should be noted that the Hirsch et al. study focuses on transport, and although it is pervasive throughout the economy, the study does not consider the broader aspects of planning and developing the built environment. If these and other socio-economic elements were added to the list, the range of adaptive actions would increase to include: inner city living in compact urban form; transit oriented development; behavioural change to a public and active transport focus; alternative and lower embodied energy building materials and construction processes. Renewable energy sources would feature more prominently, with local distribution grids. In the longer term, adaptive measures—including those listed in Table 3.1—will become much more important as the inevitability of oil supply constraint becomes a reality. This is also analogous to climate actions that have transitioned from mitigation to an adaptation focus, as in the development of a Queensland Climate Adaptation Strategy[20]. It is considered that the modified mitigation and adaptation terminology is a useful way to categorise and analyse oil depletion actions, but in a flexible application of the model.

In relation to physical mitigation, Hirsch et al. (2010: 109) note that 'performing a meaningful analysis of the best-case mitigation of world oil production decline is the selection of the most important variables, while making reasonable assumptions on other important factors'. They acknowledge that analysis is hampered by the 'multitude of complexities and unknowns' surrounding oil production decline, but postulate a 'worldwide crash program' of mitigation starting from a business as usual situation (2010: 109). The program assumes all countries would act with equitable goodwill in the program, which the authors caution is unlikely as oil exporting nations will withhold supplies to suit national objectives, including their own longer term resource needs. However, the program including all the component 'wedges' could have the mitigating effects shown in **Figure 3.7**, based on a four per cent decline rate. A successful implementation could arrest the loss to the order of 20 mb/day.

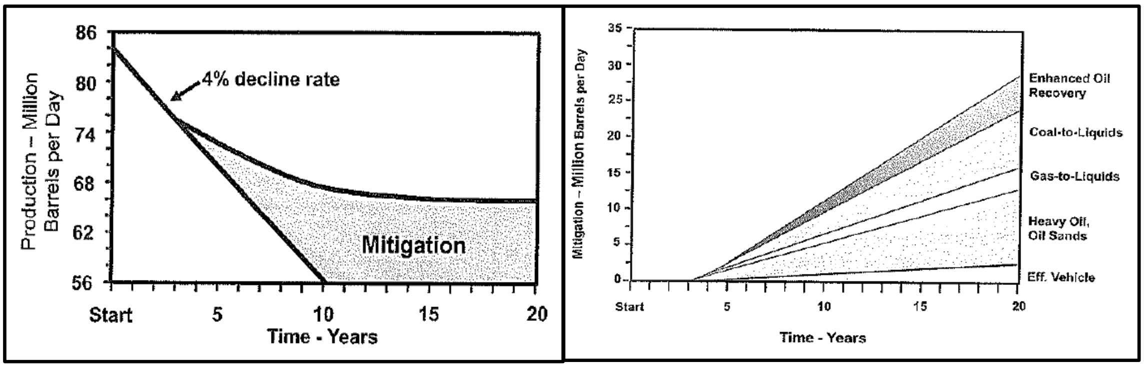


Figure 3.7: Program of physical mitigation oil decline measures in Hirsch model

Source: Hirsch et al. (2010: 129-30)

This underlying caution supports this research that the act of mitigating oil demand at the local level may actually cause economic disadvantage, while allowing a business as usual approach elsewhere, at both intra- and inter- national scales. Such a view is in keeping with the notion of oil depletion being a global wicked problem, as discussed in section 3.1.1. Hence, there will be economic winners and losers in the post peak oil scenario, which will gradually impact on the economic performance of cities and hence affect future urban development. This scenario is supported by many of the commentators cited in this thesis and makes an urgent transition to adaptive measures all the more important. An adaptive strategy, however, is likely to pose fewer risks from adverse external threats to the national economy. It will also contribute in a

20 This is currently under policy development as an initiative of the ALP state government and expected for release in 2016.

more positive way to climate change mitigation. Such adaptive measures would adjust in ways to increase resilience of human settlements to oil supply depletion by:

- planning urban development to reduce dependence on the oil economy
- taking advantage of opportunities created by science and technology
- coping with consequences of reducing supply in an oil-constrained future.

3.3 Oil-related flows to urban residential development

Urban metabolism forms the basis for the conceptual framework in this thesis to investigate oil and gas flows in urban development. The model developed in section 1.3.2 and shown in Figure 1.3 is a useful tool to analyse the flows of energy, water, food and materials into settlements and the waste outputs from them (Yencken & Wilkinson 2000; Girardet 2008; Pinho et al. 2010; SUME 2011a). In accordance with the initial conceptual framework and the analysis in section 3.2.3, this thesis focuses on *oil supply adaptation* as an intervening factor defined in section 1.3.3, which includes key substitute energy, materials and products available at the selected city. Adaptation will influence the key oil-related inputs noted in the model. This section describes how the urban metabolism model is used with material flow analysis, as a partial life cycle analysis, to assess the oil-related stocks and flows in urban development, and applied in the pilot case studies in Chapter 5. Detailed information about building materials of interest to this thesis is included in **Appendix B** in the enclosed CDROM**.**

3.3.1 Application of urban metabolism model to development

This section elaborates on the urban metabolic impact analysis theoretical framework used for this study, which requires comprehensive and complex methodologies such as variations of life cycle assessment (LCA) (Pinho et al. 2010). LCA focuses on inputs and outputs in a defined system. A recent major European study applying the urban metabolism model to four cities is relevant to this research (Pinho et al. 2010: 1). The Sustainable Urban Metabolism for Europe, involving ten partners from nine countries, is a three year investigation of the material flows at city scale in Vienna, Stockholm, Oporto and Newcastle UK. It analyses 'the relationship between urban form and urban metabolism in a long-term development perspective to 2050 … demonstrating the impact of urban form on resource flows' (SUME 2011a: 8). The aim is to reduce energy and material flows to achieve more resource efficient and lower carbon cities. The study acknowledges the difficulties in such analyses as similar studies until this time have been 'pioneering and phenomenological in their scope' (SUME 2011b: 7). The study focuses on the key determinants of urban energy use—transport and buildings flows and stocks—as the most relevant urban flows. The SUME project lends support to the objectives of this study and methods focusing on buildings and transport, albeit it is on a much smaller scale. That the urban metabolism approach is suitable for this research problem was confirmed by Dr Julia Steinberger (pers. comm. June 2011), who was a member of the study team. However, the aim of this study is the antithesis of the SUME project in that it investigates the potential impacts of oil resource depletion on urban form.

Life cycle and material flow analysis

In the assessment of a system and activity, research by Pinho et al. for the SUME project strongly suggests that methodology should be structured 'depending on the specific nature of the situation and should not follow, in a rigid way, a number of standardized procedures' (Pinho et al. 2010: 4). The heart of LCA is the life cycle inventory (LCI) that compiles and quantifies all the inputs and outputs of materials and elementary flows. LCA is an evolving discipline and is difficult to undertake for complex developments (Birkeland 2008: 137). The global standard procedures and guidelines for LCA are set out in ISO 14040:2006 and ISO 14044:2006 (ISO 2006a, 2006b). This thesis has researched several academic and practitioner works including Birkeland (2002, 2008), Sobotka and Rolak (2009), Pinho et al. (2010), Weisz and Steinberger (2010), to identify the most appropriate method under the umbrella of life cycle impact assessment in ISO 14040:2006. A similar form of analysis of urban metabolism, but more relevant to this thesis, is material flow analysis (MFA). Brunner and Rechberger (2004) published a detailed handbook on using MFA for resource management within a defined system. MFA can be directed at tracking 'a particular substance or material throughout a system, production process or supply chain' (Birkeland 2008: 136). Brunner and Rechberger (2004: 141) maintain that 'MFA is directed towards reducing the number of substances of study as much as possible to maintain transparency and manageability'. Their analysis approach suits this research problem, as confirmed by Professor Birkeland (pers. comm., 15 June 2011).

A limited MFA approach has been adopted to evaluate oil and gas related inputs for a life cycle inventory. How the key MFA terms are defined and applied to this research, and the protocol to be followed, are set out in detail in **Appendix A**. LCA takes into account the entire life cycle—a 'cradle-to-grave' approach. MFA can also be applied to 'cradle-to-gate' and 'cradle-to-installed' studies (BPIC 2010: 16; ISO 2006a: 19). The end point for the purpose of this research is the 'installed' condition for a completed development. There is no requirement for the purpose of this thesis to assess the detailed outputs and impacts, as is the case in a full LCA procedure—e.g. to determine CO_2 emissions for climate change mitigation, although this is a relevant consideration.

Oil input data is collected mainly by reference to commercially available secondary sources of data, as detailed in section 1.2.1 of Appendix A. Together with the CSIRO, the Green Building Council of Australia, and the Building Products Innovation Council (BPIC) the Australian Life Cycle Assessment Society (ALCAS) is developing a life cycle inventory database for material stocks and flows in the Australian context. Although ALCAS is preferred as the prime data source, the database is still a work-in-progress in late 2013. This delay has caused significant problems in the thesis research for the case studies in providing the life cycle inventory data and validating the inputs. An Australian LCA reference book by Crawford (2011) compensates with a general embodied energy index for materials at **Appendix C**; and a comparison LCI case study for a typical suburban single storey Australian house, which is similar to case study A.

3.3.2 Building materials and energy flows

In 2006, the Australian Greenhouse Office (AGO) commissioned a study to provide information to the Australian Building Codes Board on improving the environmental sustainability of building materials (AGO 2006). The study considered that the conventional building industry is engaged in taking materials and components that have been manufactured or mined 'upstream' and assembling them into structures. **Figure 3.8** summarises this industrial system as a metabolic life cycle process model.

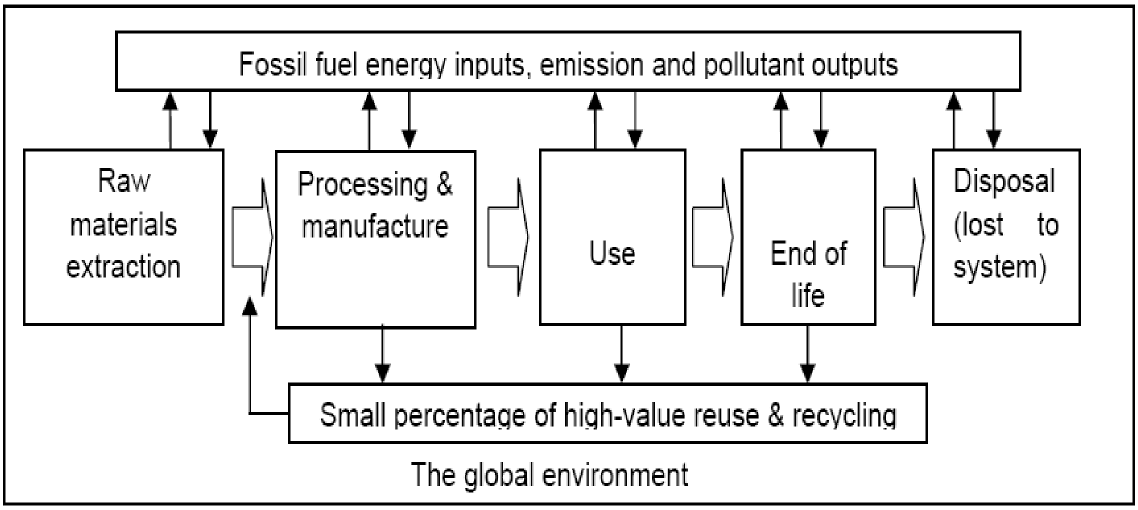


Figure 3.8: Simplified conventional industrial systems schematic

Source: AGO (2006:13)

The diagram indicates essentially a linear flow in the system that results in building stock, with pollutant outflows and end of use recycling of high value materials. It includes the raw materials extraction and the energy flows into the system. The study boundary was defined as the 'products and materials incorporated in the building fabric to Certificate of Occupancy stage i.e. including floor finishes and paint, fixed joinery, building reticulation of potable and waste water, and cabling for power'. The system could therefore be regarded as a 'cradle-to-installed' approach. Building materials were defined for the AGO study as 'materials and products used in the construction or assembly of building components' (AGO 2006: 9) and is adopted for this research. **Table 3.2** reproduces table 1 of the AGO study to show the building components (left column) and related materials (right column) included in the study (AGO 2006:10). The key building materials listed include bricks, cement and concrete (blocks and reinforced forms), paints, polyvinyl chloride (PVC), steel, aluminium and glass.

Table 3.2: Building components and material in typical Australian buildings

Source: AGO (2006:10)

Products	Petroleum Liquids	Petroleum Gas	Natural Gas
Aluminium	transport energy		energy
Asphalt	feedstock		
Bricks	transport energy		energy
Cement	transport energy		energy
Concrete blocks	transport energy		
Concrete (poured)	transport energy plasticizers feedstock		
Paints*	feedstock	feedstock	feedstock
Plastics*	feedstock	feedstock	feedstock
Steel	transport energy	energy	energy
Timber—natural form	transport energy		
Timber—particle board form	transport energy	feedstock	feedstock

Timber is not included in the Table, but it is a key building material, which also relies on oil in the harvesting and treatment processes. Also excluded is bitumen, which is an important road surfacing material that is combined with fine gravel to make asphaltic concrete. Oil and natural gas feature in the manufacture of these building materials, either as a feed stock or energy input as summarised in **Table 3.3**.

Table 3.3: Construction and building materials—oil and gas inputs

Source: After Wittcoff, Reuben & Plotkin (2004)

Building components	Building materials
Sub-floor foundations	Sand / mud / earth
External and internal walls (including paint and renders)	Rock / stone
External and internal floors (including floor finishes and surfacing)	Concrete / cement / mortar
Insulation	Clay bricks and tiles
External and internal doors (including framing)	Steel
Windows (including framing)	Aluminium
Ceilings	Glass
Roofing	Plasterboard
Electrical	Ceramics
Cabling for power (within building envelope only)	Plastic
Plumbing	Fibreglass
	Plastics
	Paints and other finishes
Plumbing fixtures (within building envelope only)	Plastics and metal

* Common plastics in land development and construction include: PVC and polypropylene sheet and pipes; polyurethane and polystyrene foams; high and low density polyethylene (HDPE and LDPE) sheeting and films; ABS (acrylonitrile-Butadiene-Styrene) clear sheets; acrylics in paint; and PVC in many forms for internal fitout, flooring and furniture.

The aim of the AGO study is to improve the environmental sustainability of building materials. What constitutes a 'sustainable' product or material has been the subject of intensive study (e.g. Betz et al. 2001; Smith Cooper 2003; Weidema 2000). Numerous guidelines and techniques specific to buildings assess the environmental credentials of construction materials (Woolley et al. 1997; Berge 2000). The Betz et al. study cautions 'that there remains no agreement as to what is empirically 'sustainable', with a number of barriers to this, including resource stocks of global natural systems that are not well quantified' (Betz et al. 2001: 327). Amongst several sets of 'eco-efficiency principles', the World Business Council for Sustainable Development (WBCSD 2006) suggests:

> Eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity.

WBCSD's eco-efficiency principles form a basis in Chapters 4 and 5 for adapting urban development to global oil depletion and they fit into the urban metabolism model in **Figure 1.2**. The seven WBCSD principles (WBCSD 2006: slide 23) are:

1. Reduce material intensity
2. Minimise energy intensity
3. Reduce dispersion of toxic substances
4. Undertake recycling
5. Maximize sustainable use of renewables
6. Extend product durability
7. Increase service intensity

Principles 1, 2, 5 and 6 are directly related to oil depletion, both as a desirable adaptation measure, and as an unavoidable consequence of a diminishing resource. Reducing material and energy intensity requires less oil inputs. Maximising the use of renewable forms of energy reduces the demand for oil and gas. Making use of more durable materials and components extends their life cycle, thus decreasing the capitalised embodied energy per annum. Alternative building materials are discussed in Appendix B and Chapter 4. The sustainability principles have desirable effects in promoting the reduction of oil and gas demand, with concomitant economic and environmental benefits.

Building materials energy inputs

The AGO study, (see **Figure 3.10**), shows that 'oil will make up approximately 32% of energy use in building materials and construction (two thirds of this is direct energy use in construction)' (AGO 2006: 71). Of this input, an increasing proportion will be from imported oil, as Australian domestic production peaked in 2000-01 and had declined by 30% by 2006. Natural gas is abundant in Australia and is projected to comprise 22% of energy in building materials by 2055. Oil and gas are projected to account for some 120 PJ (54%) of total 230 PJ building energy demand (AGO 2006: 71).

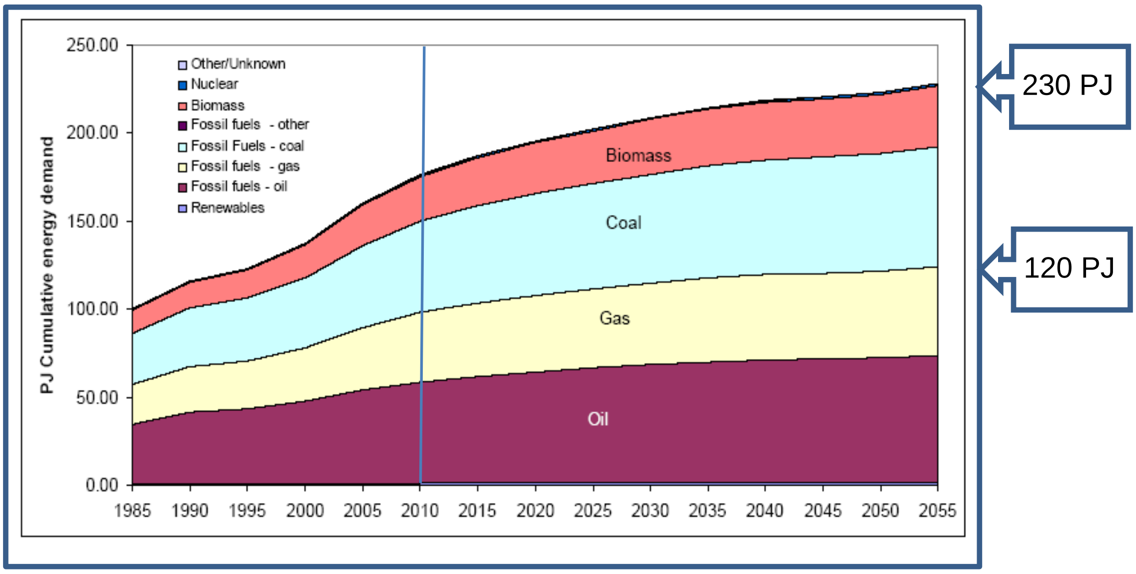


Figure 3.9: Cumulative energy demand by source for all Australian building sectors 1985-2055

Source: AGO (2006: 71)

Figure 3.9 indicates only a modest growth rate in oil and gas inputs from 2010 to 2055. The AGO study takes into account the scope during that period for efficiency improvements. However, 'it is unlikely that the industry could isolate itself from more general economy-wide impacts of energy scarcity' (AGO 2006:72). Nevertheless, the study predicts *increasing* inputs of oil in the post-peak oil era, whereas gas and renewable sources will be needed to *decrease* reliance on oil in that period.

Embodied energy

The AGO study notes that 'in bulk materials terms, concrete, steel, aluminium and brick are typically the most significant contributors to global warming impacts of construction because of the energy inputs to the production of these materials—the embodied energy—as shown in **Figure 3.10a** (AGO 2006: 40).

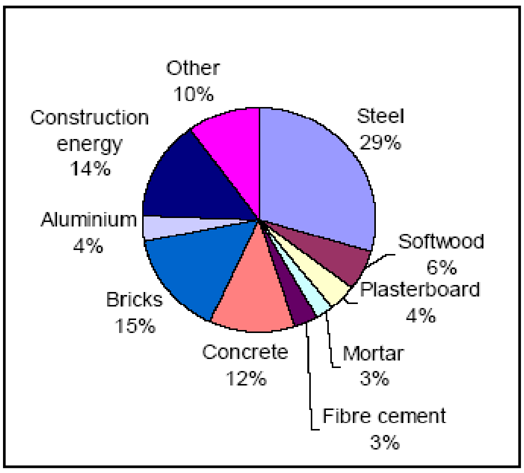


Figure 3.10a: Global warming impacts by material for all building sectors for 2005 Source: AGO (2006: 40)

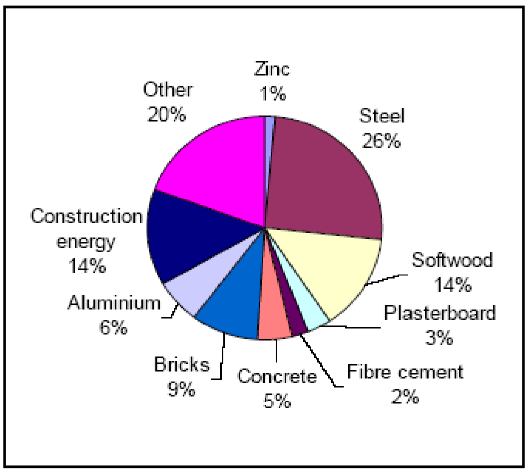


Figure 3.10b: Cumulative energy demand by material for all building sectors 2005 Source: AGO (2006: 46)

Figure 3.10a shows that the global warming impacts are evenly spread across a large number of materials. 'Steel, bricks, concrete and aluminium are the largest contributors because of the energy inputs to the production of these materials. The dominant contributor to global warming is CO_2; the only other significant contributor being methane emissions from landfill of organic materials, principally wood. The small amount of methane creates this impact because the global warming potential of methane is much higher than that of CO_2' (AGO 2006: 39). As noted above, the AGO estimates that 'oil will make up approximately 32 per cent of energy use in building materials and construction (two-thirds of this is direct energy use in construction) (AGO 2006: 71). Other studies which have found the direct energy used on site to assemble the building is approximately 5–13 per cent of total embodied energy (Crowther 1999: 2).

Figure 3.10b shows 'cumulative energy demand is similar to global warming impacts, except that plastics play a larger role (in the 'other' category) due to fact that oil and gas used as the feedstock for plastics are included in the total embodied energy figure' (AGO 2006: 45-6). Note also from these charts that softwood used in building has a significant embodied energy and that concrete and brick materials have a smaller proportion of embodied energy compared with CO_2e emissions impact. Curiously, these elements exclude the transport component, considered in that study to be small. The AGO study highlights the impact of all assessed construction materials as being equivalent to 18 million trees grown to maturity to offset the embodied greenhouse impacts of one year's construction; and 'a cumulative energy demand equivalent to 15% of annual household energy consumption for every Australian'. However, 'greenhouse and energy impacts from materials assessed are dominated by operational energy at a ratio of 9:1 over all building types' (AGO 2006: 56).

The AGO study also notes that the area of new residential houses has increased by some 40 per cent between 1985 to 2005 to an average of 258 m^2 and consequently has more than offset any efficiencies in material intensity per square metre (AGO 2006: xiv). Dwelling area is relevant to this thesis and will be considered in a case study of typical buildings in the urban residential typology in Chapter 5. Estimates of embodied energy and life cycle energy use have been made by several technical agencies and research establishments. Weisz and Steinberger (2010: 187) conclude from a wide ranging literature review of energy and material flows in global cities that 'buildings are the largest single sector in energy end use world-wide' when construction, maintenance, operational use and demolition (full life cycle) are taken into account. The energy use in buildings is responsible for 26 per cent of Australia's greenhouse gas emissions and is the primary cause of peak energy demand on the electricity network according to CSIRO research (CSIRO 2011).

Research relevant to Australian circumstances includes Australian Institute of Architects (2009), Urban Ecology Australia (2006), CSIRO (2009) and the Australian Government *Your Home Technical Manual* (2008). This manual defines embodied energy and gives examples for commonly used building materials, drawing on CSIRO (**Figure 3.11**) data that highlights concrete, steel and plastic as key materials.

Embodied energy *is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery. Embodied energy does not include the operation and disposal of the building material. This would be considered in a life cycle approach. Embodied energy is the 'upstream' or 'front-end' component of the lifecycle impact of a home.*

Source: Australian Government (2008: 136-139)

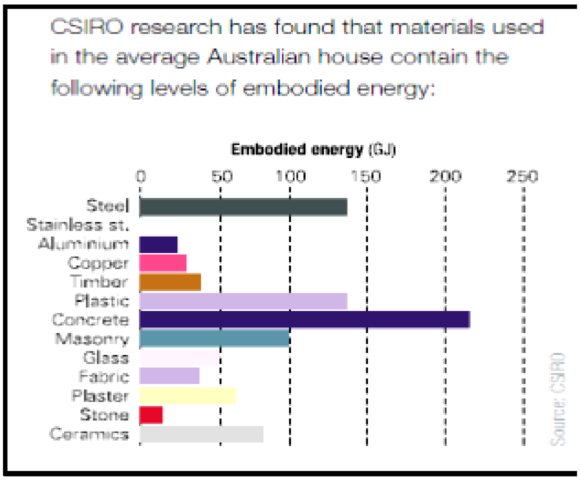


Figure 3.11: Embodied energy chart for an average Australian house

Source: Australian Government (2008: 138)

The manufacturing sector also uses energy intensive high temperature firing processes for mineral processing, cement production, brick and glass making, which comprise approximately 15 per cent of end energy use in the sector. Intermediate and low temperature processes comprise 47 per cent (Yencken and Wilkinson 2000: 80). Note that neither of these processing activities accounts for energy inputs in transporting raw materials, feedstocks or finished products. Conversion of oil-based heating to other sources would be necessary in an oil-constrained era.

3.3.3 Key oil and gas inputs to urban residential development

This section summarises the findings of the MFA analysis. In accordance with the MFA scope definition, the key oil and gas related inputs to urban residential development, detailed in **Appendix B**, become inputs into the case study. Commercially available secondary source data enable the inputs in building construction to inform the case studies in a way that is consistent with other LCA studies. Oil input data are collected with reference to the LCI inventory databases noted in section 1.2.1 of **Appendix A**, with preference given to the AusLCI or BPIC LCI and supplemented by data from other sources. The data includes an inventory of main building materials and components relevant to this study and petroleum related inputs in **Appendix B**. The input summary tables are reproduced as **Tables 3.4** and **3.5** for:

a. materials made directly from oil—e.g. bitumen, fuels, lubricants
b. products made indirectly from oil or gas as a feedstock—e.g. plastics, rubber, paints
c. oil and gas used in heating material as a process—e.g. in cement manufacture
d. embodied energy (if known) on a per unit of quantity (energy intensity) basis.

Table 3.4: Oil-related inputs to residential land development and building construction

URBAN DEVELOPMENT COMPONENTS	KEY OIL INPUTS	Inputs category		Input energy
		Direct	Indirect	MJ/unit
Road surfaces: - Major (M) - Local (L) - Footpaths (F) - Kerb & Channel (K&C)	All - plastics – waterproof sheet/pipes and rubber components (e.g. tyres).	No	Feedstock	
	M – concrete aggregates – quarrying	No	Diesel 4-5 l/m^3	160-200MJ/m^3
	M, L, F– Bitumen (asphaltic concrete)	Yes		Bitumen: 53 MJ/t
	M, L, F– Heavy oil as a sealant and dust suppressor.	Yes		Oils-variable
	F, K&C – Poured concrete insitu.	No	Diesel 4-5 l/m^3	160-200MJ/m^3
Engineering services: - Water (W) - Sewer (S) - Electricity (E) - Communications (C)	All – Oil based plastics and rubber components (e.g. pipes, conduits, cables).	No	Feedstock	Highly variable
	All – Oil based seals, glues, lubricants.	Yes		
	All – Transport and installation related inputs (plant and equipment – most of which is mobile diesel powered, including generators).	Yes		Diesel: 40MJ/l
	W & S – uPVC pipes.	No	Feedstock	PVC: 157GJ/t
	E & C – Insulated housings and coatings, insulators, circuit boards, transformer coolants.	No	Feedstock	PVC pipes: 100mm=0.266 GJ/m length
Building construction: - Sub-structure (SS) - Structure (S) - Wall cladding (C) - Internal walls (IW) - Flooring (F) - Windows (W) - Roof (R) - Paint & coatings (P) - Insulation (Ins)	SS, S – Plasticisers in concrete.	Yes		
	C – Concrete products – quarrying of aggregates, sand dredging.	No	Diesel plant in quarry, dredge	
	C – Polystyrene foam panels.	No	Feedstock	
	C, IW – Timber framing – forestry chemicals.	No		
	– Timber harvesting and processing.	Yes		460 MJ/m^3
	W – uPVC window frames.	No	Feedstock	
	W – Glass manufacture.	Yes		Glass 49 MJ/m^2
	R – Bitumen waterproof seal.	Yes		
	F– Plastic resins in paints and coatings.	No	Feedstock	
	In – Polyester and polystyrene based insulation.	No	Feedstock	
Building systems: - Electricity systems - HVAC systems (H) - Water supply (W) - Stormwater management (S) - Other - e.g. solar PV, solar hot water systems, communications, (O)	- Oil-related inputs are ancillary to the electricity systems, including inputs into manufacturing of materials for components; and transport and installation related inputs (plant and equipment – most of which is mobile diesel powered, including generators).	Yes for diesel power.		Highly variable
	- Oil-related inputs are ancillary to the HVAC systems, including inputs into manufacturing of materials for components and transport related inputs.	Yes for diesel power.		
	- Water supply involves plastics in piping and diesel powered	Yes for diesel	Plastics Feedstock	

URBAN DEVELOPMENT COMPONENTS	KEY OIL INPUTS	Inputs category		Input energy
		Direct	Indirect	MJ/unit
	machinery for trenching. - Stormwater infrastructure involves plastics in piping and sheeting; diesel powered machinery for trenching. - Other systems are similar to the above.	power. Yes Yes	Plastics Feedstock Plastics Feedstock	
Waste management: - Solid - Liquid - Gaseous	- Waste management systems are similar to the above.	Yes	Plastics Feedstock	Highly variable
Building landscape: – Hardscape elements	- Building landscape systems are similar to the above including plastics – in sheet and pipe form.	Yes	Plastics Feedstock	Highly variable

TABLE 3.5: Gas-related inputs to residential land development and building construction

URBAN DEVELOPMENT COMPONENTS	KEY GAS INPUTS	Inputs category		Input energy
		Direct	Indirect	MJ/unit
Roads: - Major (M) - Local (L) - Footpaths (F) - Kerb & Channel K&C)	All – plastics- waterproof sheet and pipes. F – Poured concrete insitu. K&C – Poured concrete insitu.	No	Feedstock (Gas kilns (Plasticisers	 6600 MJ/m³
Engineering services: - Water (W) - Sewer (S) - Electricity (E) - Communication (C)	All – Oil based plastics and rubber components (e.g. cables, seals, glues, lubricants). W & S – PVC pipes. E & C – Insulated cables, housings and coatings, insulators, circuit boards, transformer coolants.	No	Feedstock Feedstock Feedstock	Highly variable
Building construction: - Sub-structure (SS) - Structure (S) - Wall cladding (C) - Internal walls (IW) - Flooring (F) - Windows (W) - Ceilings (Ce) - Windows (W) - Roof (R)	Plastics – Sheet and pipe. SS, S – Indirect in cement manufacture. SS, S – Plasticisers in concrete. SS, S – Steel manufacture. C – Polystyrene foam panels. C – Brick cladding. C, IW – Timber framing – forestry chemicals. – Timber harvesting and processing. W – uPVC window frames. W – Glass manufacture. R – Steel and tile roofs – gas in manufacture. IW– Plasterboard – manufacture heating.	No Yes No Yes No Yes No Yes No Yes Yes	Feedstock Gas fired kilns Plasticisers Gas heating Feedstock Gas fired kilns Feedstock Gas fired kilns Feedstock Gas heating Gas heating Gas heating	6600 MJ/m³ 3247 MJ/t 2260 MJ/t 580 MJ/m³ 20 MJ/m² 9 MJ/m²

URBAN DEVELOPMENT COMPONENTS	KEY GAS INPUTS	Inputs category		Input energy
		Direct	Indirect	MJ/unit
- Paint & coatings (P) - Insulation (Ins)	Ce - Plasterboard – manufacture heating. F– Plastic resins in paints and coatings. In – Polyester and polystyrene based insulation. In – Glass fibre manufacture.	 No No Yes	Gas heating Feedstock Feedstock Gas heating	9 MJ/m^2
Building systems: - HVAC systems (H) - Water supply (W) - Stormwater management (S) - Other (O)	- Gas-related inputs are ancillary to the HVAC systems, including inputs into manufacturing of materials for components and transport related inputs. - Water supply involves plastics in piping. - Stormwater infrastructure involves plastics in piping and sheeting. - Other systems are similar to the above.	Heating	Feedstock	Highly variable
Waste management: - Solid - Liquid - Gaseous	- Waste management systems are similar to the above including plastics in sheet and pipe form. - Heating processes.	Heating	Feedstock	Highly variable
Building landscape: – Hardscape elements	- Building landscape systems are similar to the above including plastics in sheet and pipe form.	Yes/No		Highly variable

3.3.4 Direct energy inputs

Information for this section has been obtained from the construction managers for the detached house and the six storey apartment building case studies to provide qualitative evidence for oil and gas as direct energy inputs to residential development:

- transport to site (e.g. by truck transport)
- building processes
- on-site energy consumption (where known).

Essential transport-related inputs

The road haulage of materials and components is an important aspect in construction that is difficult to accurately quantify. Construction related transport is heavily dependent on diesel power. This includes transport of sand and gravel substances; cement to premixed batching concrete plants; concrete transit mixers; transport of all building materials and components to the site; and removal of all waste from the site.

The general goods delivery arrangements by sub-contractors for house building vary considerably between each project. Delivery of small items is also an indeterminate variable as the method and aggregation of items varies not only on a case-by-case basis, but also on a temporal basis. Some items are the responsibility of the tradesperson to obtain and deliver to site; others are provided by the prime or sub-contractor. Items from a major supply warehouse may be delivered by the supplier to a number of sites in the same trip, or collected by the builder. However, energy input to goods delivery is all related to vehicle operation, which has a range of energy efficiency and load efficiency factors.

Materials and goods delivery for commercial scale building projects can take advantage of economies of scale. Nevertheless, the volume of goods is also larger, so that (for example) a continuous pour for a large concrete floor can take 100 mixer loads from multiple sources, spread over a citywide batching plant operation.

The workforce for domestic construction projects tends to be strongly self-sufficient, carrying their own tools and equipment to and from the site on a daily basis (Norimi, V, pers. comm., 9 June 2012). For this reason, use of public transport is often not practical. Moreover, the workforce may also live in places remote from worksites, especially greenfield projects. Early start times of 6:30am also makes public transport inconvenient or unavailable. While trades people may try to live close to work, the geographic variety of sites and the shifting temporal nature of the suburban housing market as subdivision projects are completed, makes it difficult to achieve such a desirable aim under these working circumstances.

In contrast, commercial scale medium and high rise building projects rely on more site-oriented storage of plant and equipment, which makes workforce transport less reliant on private vehicles. However, the medium rise apartment building construction manager advised that early start times and convenience factors make private transport the preferred mode choice, unless restricted parking on or near the site is an issue. Once the basement level of such a building is operational, trades can set up secure storage and work areas to effectively function as on-site factories for making and assembling building components.

Essential related plant and equipment

Site-based plant and equipment for construction is generally powered by mains electricity wherever available; and by diesel fuel powered electrical generators where unavailable. On domestic scale building sites the first action is to install a temporary power pole. On construction sites for commercial scale building, 3-phase electric power is required for plant such as main cranes and lifts/hoists. This is often not available until the necessary sub-stations are installed which may be several months, or even years, into the project schedule. Mobile plant is normally powered by diesel/petrol internal combustion engines or LPG fuelled engines (e.g. concrete pumps). Hand held equipment is predominantly battery powered (e.g. drills and saws), requiring single-phase electric power for recharging. The power consumption for battery operated hand tools is excluded from the calculations, because while some recharging electricity would be supplied on-site, most would be overnight charging off-site. The off-site mains electricity currently has only a small gas input in the Queensland coal-fired power generation system. Some equipment is also powered by compressed air which could be operated by a diesel or electric powered compressor.

The fall back energy solution is normally diesel power for reasons of energy efficiency and cost effectiveness. In greenfield land development, it is frequently the default power source. All truck or tractor based plant and equipment is diesel powered—e.g. crane trucks, mobile cranes, excavators, loaders, trenchers. This makes building processes highly dependent on oil.

On-site energy consumption

The direct energy consumption for construction of the representative residential typology is estimated in the case studies at Appendices D-G. The single storey detached house of the type in case study A is of the order of 350 kWh of electricity at peak rates when taken from mains power, equivalent to 1.26 GJ. In relation to the three and six storey apartment buildings in a greenfield situation as case studies B and C, the on-site power was provided by diesel generators until 3-phase permanent mains power could be connected. The construction manager considered the generators to be more energy efficient than mains electricity and provided fuel data sheets as evidence. In fact the mains power was not connected until the end of the project. The resulting energy input was about 400 GJ and 1100 GJ respectively, or equivalent to about 26 GJ or over 7MWh per apartment in each case. This is over 20 times the direct energy input for the house. In addition, an unquantified volume of oil for diesel powered plant and equipment include dewatering pumps, concrete pumps and helicopter vibrators used on the concrete floors is omitted due to lack of operating data.

In relation to the case study D 30 storey residential tower on an infill central city site, the on-site 3-phase permanent mains power was available from commencement and this project did not experience the delays of the greenfield cases. The energy inputs are larger for the high rise tower, however, the mains electricity currently has only little oil and some gas input in the Queensland mainly coal-fired power generation system. Diesel powered plant and equipment including concrete pumps and helicopter vibrators are used on the concrete floors is omitted due to lack of operating data.

Another case study omission in energy inputs is for the building lifts, which is considered to be a small missing factor, as the lifetime operating energy far outweighs the embodied energy. One estimate is that a residential building served by lifts consumes 5-15 per cent of the total operating energy of the building; Roaf suggesting a 12 storey apartment building with two lifts 'might use up to 40,000 kWh' (11.1 GJ) (Roaf 2010: 35). An estimate made for this research is reported in Chapter 5 of a seven level apartment building with 10 units at two per level reveals the single lift consumed 16-18 per cent of estimated total energy. However, lifts are a distinguishing component in all residential apartment buildings over two storeys in the Australian context; and in buildings over 10 storeys two or more lifts are required. The building shape and floor plan determines the number of lifts required. Elongated apartment blocks need more lifts to service dual loaded layout arrangements, as shown in Figures E.3 and F.3 of case studies B and C. The 30 storey tower operates three lifts to a single lobby per floor.

3.3.5 Conclusions to key oil and gas inputs to development

This section has conveyed a lot of data from a wide range of sources that confirm the key materials in residential development have varying oil and gas inputs. Appendix B provides an indication of the embodied energy in the key oil and gas-related, non-transport inputs to residential land development and building construction. Oil-related inputs are summarised in Table 3.4 and gas-related inputs in Table 3.5. While steel, concrete and masonry are the most embodied-energy intensive construction materials, they are also highly durable with long lifetimes. It is important to note that the direct inputs of oil are quite limited in the non-transport energy sector (except for diesel powered construction equipment and generators). The main direct inputs are in asphalt for road surfacing and in petrochemical products such as plastics and paints. Plastics comprise a very wide range of materials from PVC products to polyester insulation. Oil is also a key component of synthetic rubber; hence there is dual input to road vehicles through essential parts as well as fuels and lubricants.

While this thesis focuses on non-transport related issues of oil depletion, from a land development and building construction viewpoint, transport issues are very important factors. This is distinct from transport aspects arising from general mobility of the population, and movement of non-construction goods and services—e.g. food delivery and commercial services. The transport factors discussed in section 3.3.4 are integral to all material extraction, harvesting, processing, manufacturing and delivery to development sites. These circumstances make the development and sustainable exploitation of alternative transport fuels to be a policy imperative. This aspect is revisited in section 4.1.3(A) analysing the intervening factors, along with more descriptive details in section 3.2 of Appendix B.

Three possible scenarios in **Table 3.6** illustrate the levels of significance of oil depletion; categorised as being manageable, significant, or critical impacts. However, the Table indicates that a transition from one scenario to a more significant one is the most probable outcome, because of uncertainty in oil data. The IEA 2013 data is subject to updating for tight oil and shale gas reserves; however the general conclusions about potential impacts over the strategic planning time horizon envisaged in this thesis research are considered to be valid.

Table 3.6: Three scenarios for significance of oil depletion impacts

Manageable impacts →	Significant impacts →	Critical impacts
Conventional oil declines, but unconventional sources are plentiful for at least the next 180 years and gas for 230 years (IEA 2013c: 72):	Conventional oil declines, but unconventional sources have proven oil reserves for next 54 years and gas for 61 years (IEA 2013c: 72):	Overinflated OPEC oil reserve estimates and continuing oil demand global increases converge to create crises in the supply chain (Rubin 2009):
• CNG, LNG gas options • Ethanol and bio-diesel at large scale increasingly replace food crops • Gas-to-liquids (GTL) and Coal-liquids (CTL) at large scale supply • Electric hybrid and all-electric vehicles available at a cost premium, but less incentive to change over • Complete transition to alternative fuel supply distribution systems • Fuel price rises to fund investments in new technology may affect non-electric mobility. However, while the transport sector benefits: • Coal still dominates stationary power generation • The global energy budget is exceeded • The CO_2 emissions rise by 20% to 2035 and beyond • Average global temperature rise exceeds the safe 2° C threshold to 3.6-6° C • Climate change impact is accelerated by rising energy demand.	• CNG, LNG gas, GTL, CTL options are available, but face more competition from demand for petrochemicals feedstock • Ethanol and bio-diesel at large scale increasingly replace food crops • Electric hybrid and all-electric vehicles are widely available as the preferred transport energy option, subject to battery costs and availability of lithium • Problematic transition to alternative fuel supply distribution systems • Fuel price rises to fund investments in new technology affect non-electric mobility. However, proven reserves are only equivalent to one about generation: • About 10 years will be required for the alternative fuel supply distribution systems and the transport fleet switch, leaving less than 50 years gas use • This is problematic given long pay-back period could exceed gas supply and rising costs • The global energy budget is exceeded and climate change is accelerated.	This scenario cannot be foreseen, hence: • Oil supply is a global wicked problem that is exacerbated by market manipulation and price uncertainty affecting investment in new supply • The actual direction will only become evident as declining global oil supply and demand cause differing price rises and are reflected in the IEA annual report and other statistics • Unless governments act in a precautionary approach, policy inertia will cause the 10 year lead time for energy switching to become crisis driven. • The incentive to make any energy switches will rely on responses to climate change and to offset increasing costs for mains electricity and transport fuels of all types. • Increasing competition from petrochemicals demand will drive up materials costs for building and construction • All aspects of building will be affected to varying degrees, but greenfield development could be most affected by transport factors and need for diesel powered construction plant and electricity.

3.4 Conclusion: dependency of cities on oil is significant

This chapter has addressed research objective 1.3 by investigating in more detail the extent of oil dependency, the global peak of production and timing, and some implications of oil depletion for urban development. The considerations also include oil supply vulnerability strategies in a comparison between oil depletion and climate change. The urban metabolism theory used to develop the initial conceptual framework in Chapter 1 is applied with material flow (life cycle) analysis in a positivist, empirical approach to describe the oil and gas inputs. The European SUME project lends some support to the objectives and methodology of this study by focusing on buildings and transport, albeit it is on a much smaller scale within a single city.

Analysis of the building stock and embodied energy flows shows the main building materials listed in Table 3.2, and detailed in Appendix B. The relevance to this research is that oil and gas feature in the manufacture of most of these materials (Table 3.3), either as a feed stock, embodied energy input, or transport input. The AGO study suggests that at the macro scale 'oil will make up approximately 32% of energy use in building materials and construction (two thirds of this is direct energy use in construction)' (AGO 2006: 71). Nevertheless, the AGO research forecasts *increasing* inputs of oil in the post-peak oil era in the Australian context, when in fact gas and renewable sources will need to contribute to *decreasing* reliance on oil in that period.

The chapter confirms that transport, land-use and buildings are major contributors of greenhouse gas emissions. Cities are major centres for energy demand, requiring large quantities of energy in both construction and operation. Implementation of climate change mitigation planning principles should embrace broader sustainable development principles and an energy transition to a low carbon economy. The terminology used in climate change research and policy makes a distinction between mitigation and adaptation actions that is fairly well understood [e.g., IPCC 2007; Garnaut 2008]. An alternative set of definitions for oil demand mitigation and oil supply adaptation is devised in section 3.2.3 and tested in a case study to categorise strategies proposed by Hirsch et al. (2010). Table 3.1 demonstrates that most Hirsch proposed mitigation measures could also have varying relevance to adaptation measures. The proposed modified mitigation and adaptation terminology is a useful way to categorise and think about oil depletion responses. The definitions warrant further peer review to gain acceptance. While the Hirsch strategies are geared to mainly transport mitigation actions, adaptive measures will become more important in the longer term future as oil supply becomes constrained. An adaptive strategy is likely to pose fewer adverse external threats to the national economy and will contribute in a more positive way to climate change mitigation. Such adaptive measures must adjust in ways that contribute to increasing the resilience of human settlements to oil supply vulnerability *and* depletion. For the purpose of this research, the above considerations lead to an approach to focus on *oil supply adaptation* as the intervening factor in the initial conceptual framework, which includes key oil and gas substitute energy, materials and products available at the City of Gold Coast. Adaptive planning measures are revisited in Chapter 7 and applied in Chapter 8.

The oil-related and gas-related inputs are summarised in Tables 3.4 and 3.5. It is important to note that direct and indirect inputs of oil are limited in the non-transport energy sector (except for diesel powered construction equipment and generators). The main direct input is in asphalt for road surfacing. The main important indirect inputs are in petrochemicals such as plastics and paint products, and in rubber products. While this thesis focuses on non-transport related issues of oil depletion from a land development and building construction viewpoint, transport issues are obviously important factors. This is distinct from transport aspects arising from general mobility of the population and movement of non-construction goods and services. Hence, the transport factors discussed in section 3.3.4 are integral to all material extraction, harvesting, processing, manufacturing and delivery to development sites. These circumstances make oil (as diesel fuel) an essential input into current urban residential development; and highlight the development and sustainable exploitation of alternative transport fuels to be a policy imperative.

This chapter completes Part 1 of the thesis research. The analysis of all the direct and indirect inputs of petroleum (oil and gas) to urban residential development leads to a general conclusion summarised in Table 3.6 that constraints on these sources would have significant impacts that would affect all types of urban development.

Therefore the working propositions framed in Chapter 2 are considered to be strongly supported that the oil dependency relationship is significant in relation to the growth of major cities. Accordingly the two Part 1 propositions are modified to a single statement:

> *Significant relationships exist between new urban residential development and oil supply constraints in the growth of major cities in the Australian context, with respect to land development, building construction and ancillary transport aspects that affect all stages of such processes; thereby requiring oil depletion adaptation strategies.*

Part 2 of the research develops this proposition in Chapter 4 by investigating the land development, building construction and ancillary transport factors; and the land use planning related regulatory framework factors that might influence urban residential forms in the context of the selected Australian city. Chapter 5 applies the urban metabolism model in the form of material flow analysis to pilot case studies of the representative residential typologies in the City of Gold Coast.

Part 2

Oil dependency of urban residential development: the empirical evidence

This next part of the thesis, consisting of Chapters 4 and 5, presents the empirical documentary and case study research for objectives 2.1–2.2 shown in the research design map extract at **Figure C**. The modified proposition established in Part 1 Chapter 3 is assessed in Chapter 4 by investigating the intervening and moderating factors in the initial conceptual framework for any relevant aspects that may modify the degree of significance in the relationship between urban residential development and key oil and gas inputs. Substitute materials and energy sources may mitigate the impacts of oil depletion. The land use planning related regulatory factors may act as facilitators or barriers in sustainable urban residential forms in the context of the reference City of Gold Coast. The planning policies are affected by the successive Queensland Government initiated planning and regulatory reforms to support development.

The technical Chapter 5 builds on the empirical research reported in Chapter 4 to apply the case study strategy in section 2 of Appendix A and report on the four pilot studies set out in Appendices D – G in the enclosed CDROM. This study enriches the answer to research question 2 by comparing the individual case findings in a cross-case analysis to draw conclusions about relative oil vulnerability relating to the residential dwelling typology described in section 2.2. The analysis of study-wide inferences applicable to the urban residential typology is important in providing empirical evidence with which to support the modified proposition. This Part also develops constructs and insights relevant to the Part 3 research.

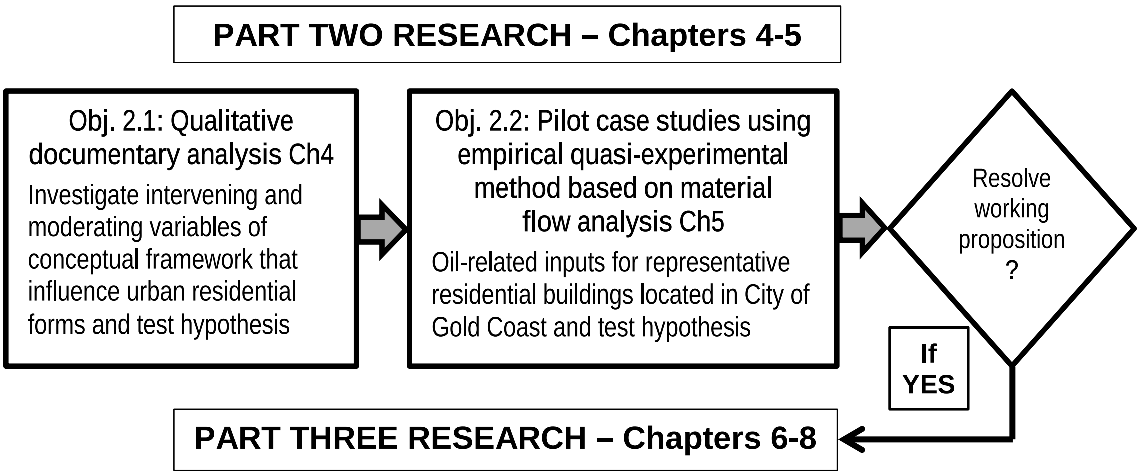


Figure C: Part 2 research design summary

Chapter 4

Intervening and moderating factors for development

> *There is no historical precedent for a single mineral coming to dominate human life as completely as petroleum since it was first extracted in commercial quantities in the mid-nineteenth century.* (Hiro 2007: 332)

This chapter initiates Part 2 of the thesis research. The working propositions in chapter 1 are considered to be strongly supported by the documentary evidence in chapters 2 and 3 and modified into a single statement for Part 1 to suggest that:

> *Significant relationships exist between new urban residential development and oil supply constraints in the growth of major cities in the Australian context, with respect to land development, building construction and ancillary transport aspects that affect all stages of such processes; thereby requiring oil depletion adaptation strategies.*

This chapter develops the proposition by investigating the intervening and moderating factors in the conceptual framework for any relevant characteristics that may modify the degree of significance in the relationship between oil depletion and urban residential development in the context of the selected City of Gold Coast. The first section identifies substitute materials and energy sources that may mitigate the impacts of oil depletion, as highlighted in the oil-related development inputs of the partial conceptual framework in **Figure 4.1**. This includes the particular circumstances of Gold Coast construction industry factors that may be affected. The second section addresses the planning related factors. The planning reforms initiated by successive Queensland Governments to support development are addressed in the third section.

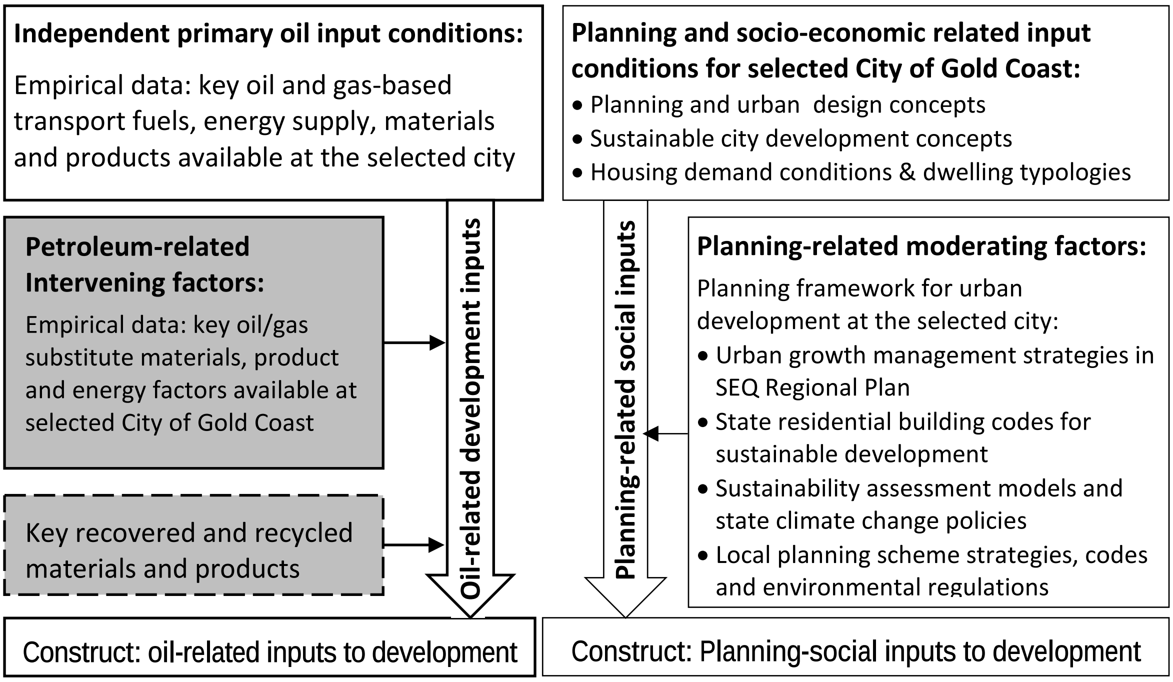


Figure 4.1: Conceptual framework highlighting intervening factors

Source: The author

4.1 Intervening factors to oil-related inputs

The intervening factors relating to oil and gas supply involved in land development and building construction include substitute materials and products (stocks), and energy (flows) available at the City of Gold Coast. The full analysis, including some key recovered and recycled materials and products, is in **Appendix B** in the CDROM and summarised below. It is not an exhaustive list and some listings are actually contradictory between categories (e.g. embodied energy in external wall cladding types).

4.1.1 Alternative construction materials and products

Section 3.3.2 of Chapter 3 introduces sustainable building materials and sustainability principles, including eco-efficiency. More durable materials, products and components extend the life cycle of buildings, thus decreasing the amortised embodied energy per annum. Although the aim should be to transition to less oil- vulnerable and more climate change sensitive materials, the reality may be less promising. For example, replacing oil-based bitumen with cement-based concrete for road surfacing conserves oil, but may create more greenhouse gases through the cement manufacture. The use of alternatives on environmental grounds and greenhouse gas mitigation requires sophisticated life cycle analysis to trace the benefits and trade-offs from cradle to cradle lifetimes (AGO 2006: xx). Suggested categories of alternative mainstream stocks in land and building development are:

A. materials that substitute for oil and gas as direct inputs;
B. substitute materials that have less embodied energy and conserve oil and gas, including reused, recovered and recycled materials;
C. materials and products that may have greater embodied energy, but are more durable or recyclable;
D. materials and products that reduce the amount of oil or gas consumed in building operation and maintenance.

A. Direct input materials examples

Some relevant examples of substitute materials for oil and gas inputs are related to road surfacing and petrochemical plastics.

Bitumen can be made from non-petroleum based renewable resources such as sugar cane, but has a higher energy penalty (apart from shipping importation). Alternative local road surfaces include steel reinforced poured concrete, pavers (concrete, brick, stone), or just compacted gravel. Pavers have been used since Roman times and are labour intensive features for light traffic roads.

Bioplastics are an emerging technology to reduce petrochemicals; however, the main focus is on bio-degradable plastic e.g. for wrapping film. Non-petrochemical based paints and coatings also are a promising field, some are reverting back to traditional oil mediums, water based paints and rendering substances.

B. Less embodied energy materials examples

Some relevant examples of mainstream substitute building materials relate to structural elements and cladding; internal flooring and hard surfaces. Reuse of any recyclable building material saves most of the initial embodied energy.

Cement making can use supplementary by-product materials including fly ash (a coal fired power station flume by-product) and ground granulated blast furnace slag. Ironically, the transition from coal to gas fired power stations will decrease the amount of fly ash. Similarly a reduction in steel production would reduce the slag available.

Lightweight autoclaved aerated concrete halves the embodied energy of standard concrete. Concrete blocks and tiles replacing clay products reduce the gas required for kiln firing, but have greenhouse gas trade-offs against natural sun-dried clay materials. Concrete to replace clay tiles and steel sheet, but durability is uncertain. Carbon fibre to replace steel in reinforcing concrete and in sheet form is an emerging technology.

Reducing the area of glass windows in external walls decreases embodied energy, but floor–ceiling windows are popular for light, ventilation and aesthetic reasons. Greenboard™ type foam cladding decreases embodied energy and improves insulation. Reduction of PVC plastic—e.g. linoleum, cork, or natural timber flooring— has environmental as well as energy benefits. Acrylic plastic is becomingly widely used to replace marble, ceramic tiles and granite for internal fittings, surfaces and flooring.

C. More durable and recyclable materials examples

More durable materials increase life cycle, but may have higher embodied energy trade-offs. For example concrete road surfacing is more durable than asphalt, but at over 30 times the initial embodied energy may not be energy effective. Face quality clay bricks do not need any surface coating treatment and are highly durable for external cladding rather than Greenboard™, but have higher embodied energy. Clay and slate roof tiles far outlast sheet steel roofing that needs replacing after 40-60 years, although tiles need sturdier framing support (timber or metal). Ceramic tiles that are far more durable than carpet floor coverings have aesthetic and insulation issues. Design for disassembly (Crowther 1999) yields more recyclable materials. Extra processing energy is required for crushing concrete, bricks and ceramic tiles into aggregate. Glass is both reusable and recyclable for making virgin glass and to make fibreglass insulation.

D. Lower operating energy and maintenance materials examples

Use of materials with lower operating energy is a mainstream practice in design of buildings. Surprisingly, timber weatherboard walls require less energy compared with all other wall types. However, all walls except 200 mm thick aerated concrete blocks need some added insulation. Roof and wall insulation reduces the operating energy required to maintain a comfortable temperature range inside buildings. Some forms of insulation are more oil and gas reliant, including: expanded polystyrene foam or beads and polyester mat (both are oil products); fibreglass batts depend on gas heat energy.

Face brick and textured concrete cladding that do not need rendering or painting reduce their maintenance over a building life cycle. Powder-coated aluminium window frames are practically maintenance free, however, timber frames are making a comeback. Wood-plastic composites reduce maintenance for external applications (e.g. decking).

4.1.2 Alternative building components and systems

The use of alternative materials such as those noted above is the subject of many guides on green building, as discussed in Chapter 3. These guides are aimed at conservation of non-renewable resources, reducing embodied energy inputs and operational energy demands over a typical building life economic cycle of 50 years (Crawford 2011: 80). The predominant building type in the Australian context is one–two storeys, concrete slab-on-ground detached dwellings. The traditional brick-veneer tile roof style is being replaced by more energy efficient, cost effective building systems:

An increasing proportion of houses are built with rendered concrete block external walls including lightweight, aerated concrete; and corrugated steel roof systems to improve energy efficiency, and reduce labour effort and costs. More recently an increasing preference is for external walls clad with 'blue board' fibre-reinforced cement, or expanded polystyrene (EPS) insulating foam panels (e.g. Greenboard™) as lightweight panels coated with fibreglass mesh and polymer-modified render. However, these wall systems are not robust to impact damage. Some use is made of tilt-up pre-cast sandwich concrete shell walls in two-three storey town housing.

Off-site manufacture (OSM) of components and assemblies is preferable to on-site construction, to reduce road transport trips and on-site labour requirements. OSM of wall framing, roof trusses and cabinetry is common practice in domestic scale building, (see section 4.4.2 of Case Study A). A study by the Cooperative Research Centre (CRC) for Construction Innovation (Blismass 2007) finds that OSM works best on large-scale projects with standardisation. Modular building systems have been promoted as a superior technique, but have yet to be taken up on any scale in Australia. The CRC study highlights constraints and barriers to increasing OSM, particularly in the cultural resistance of the house building industry and where 'a desire for particular structures or traditional finishes may inhibit OSM' (Blismass 2007: 9).

4.1.3 Alternative energy sources

Maximising the use of renewable forms of energy reduces the demand for oil and gas in transport and in building operational energy. The main alternative sources are:

A. Transport fuels
B. Electricity generation
C. Energy efficient systems and appliances

D. Lighting sources other than mains electricity
E. Manufacturing process heating

A. Transport fuels examples

Maximising the use of renewable forms of energy for transport fuels dramatically reduces the demand for oil. Gilbert and Perl (2010: 131–168) have made an extensive study of alternative transport fuels. As in the case of substitute materials, the future reality may actually be less promising than perceived. The use of corn-based ethanol for a substitute fuel, for example, has adverse effects on food agriculture and a low energy return on energy invested. Transport requirements for land development and building construction materials extend over the full range of mining, agriculture, haulage and manufacture. However the AGO study notes that 'transport energy makes up a relatively small percentage of overall energy inputs, even for transport over long distances' (AGO 2006: 6) compared with process heating and power. The main alternative energy sources to oil and gas are described in section 3.2 of Appendix B.

The current use of Ethanol as E10 or E85 for light vehicles and biodiesel for truck and machinery powerplant has an advantage in using familiar technology and delivery systems to the same fuel tanks (Gilbert & Perl 2010: 138–140). Natural gas (compressed CNG or liquified LNG) is already used in vehicles such as trucks, buses and forklifts. It is still a finite petroleum substance, but is regarded as a lower emission fuel and an interim solution until gas prices escalate beyond the peak gas period. Widespread conversion would need to set up a new distribution network system, as would the use of hydrogen fuel cells. Compressed air, although not technically a fuel, is an emerging alternative for short distance travel and for plant such as forklifts.

Battery electric vehicles (BEV) and plug-in hybrids (PHEV) are currently the preferred alternatives, but are dependent on battery technology that relies on rare earths such as lithium, and have a weight penalty (Gilbert & Perl 2010: 147). Yet 'the lithium resource base could only support 6.3 million [PHEV] in 2020' (Moriarty & Honnery 2010: 48).

B. Electricity generation examples

Electricity generation is a well-established field for alternative sources of renewable energy that is regarded as mainstream for the purpose of this research. However, all the components are currently manufactured using the oil-based economy.

Natural gas (compressed CNG or liquified LNG) is an alternative fuel in power generating plant, both in power stations and in mobile generators. As noted, it is still a finite petroleum substance, but has lower emissions than coal. Biodiesel or natural gas powered co-generation and tri-generation power systems providing electricity plus heating and/or cooling for buildings, are low emission primary or supplementary systems suitable for large apartment buildings.

Of the renewables, solar PV and solar thermal localised distributed systems as primary or supplementary systems for hot water and power are current practice in residential buildings. Wind turbine generators as supplementary systems have some potential in suitable urban settings. Solar thermal has significant potential for baseload power while geothermal heating and cooling has some potential.

C. Energy efficient systems and appliances examples

There are numerous examples of energy efficient systems and appliances. Household appliances such as heaters, washing machines and dryers and electronic items are not relevant to this research. Two examples of systems below as a representative sample include solar air conditioners using solar PV or solar thermal sub-systems to provide the power; and regenerative lift systems use braking energy to feed back into the electricity supply to conserve a building's total operational energy (Roaf 2010: 35).

D. Lighting sources other than mains electricity examples

Examples of lighting are linked to solar PV with the possibility of direct current house wiring to LED lighting, as well as presently using alternating current inverters.

E. Manufacturing process heating examples

Alternative forms of energy in manufacturing utilise solar PV and thermal electric power; waste heat from by-products and landfill methane; and greater use of coal seam gas. The latter option relies on a continuing rollout of pipeline infrastructure.

4.1.4 City of Gold Coast construction industry factors

At 30 June 2011 the estimated resident population of Gold Coast City was 514,000 persons (Queensland Treasury and Trade 2013), as Australia's sixth largest city and the tourism capital, as highlighted in **Figure 4.2**. The regional share of employment collated by the Australian Government Department of Education, Employment and Workplace Relations (DEEWR) (2013) at **Figure 4.3** shows the Gold Coast construction industry is the second biggest sector after retail trade, with 14.0 per cent and 14.2 per cent respectively of the 392,800 regional employed in the year to February 2013 (DEEWR 2013). This is significant because it confirms the historical importance of construction after retailing in the Gold Coast economy. Both industries have been part of the 50 year tourism boom that has been the hallmark of the coastal strip (GCCC 2010e: 6).

Figure 4.2: Surfers Paradise – the tourist heart of the Gold Coast

Source: Photo by the author

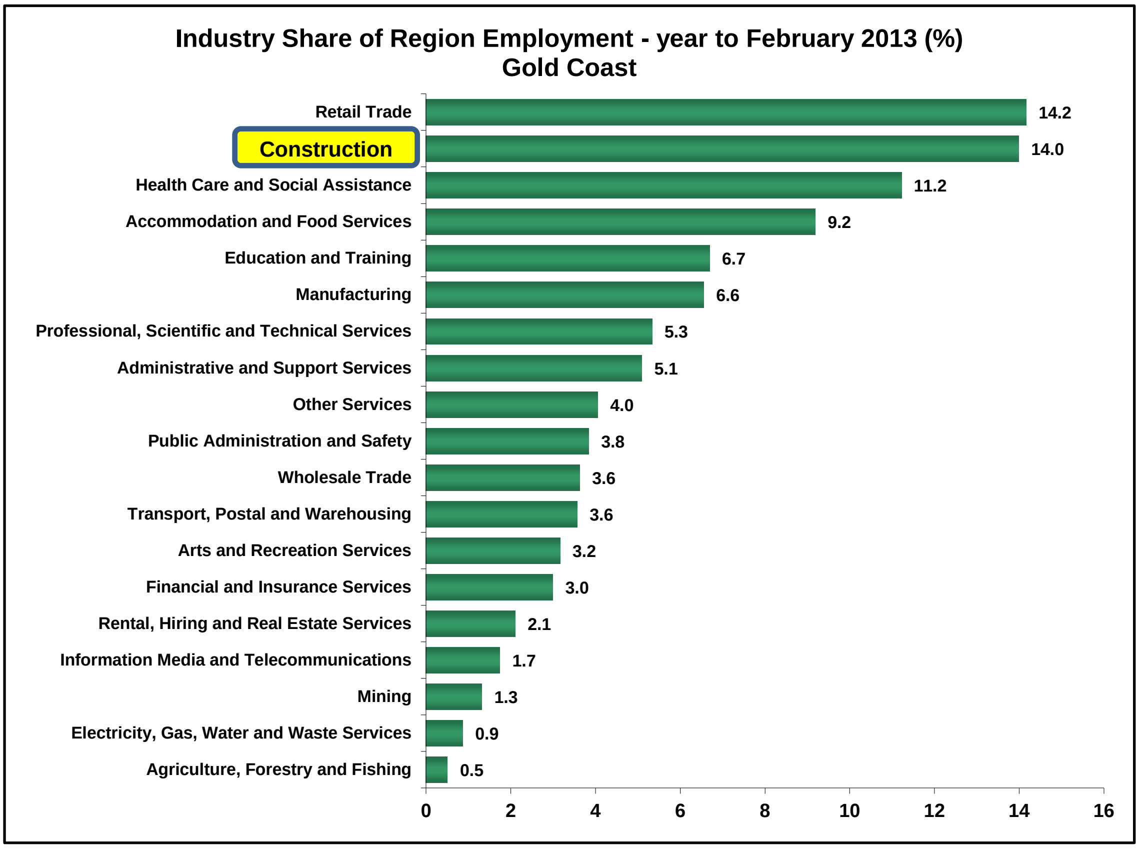


Figure 4.3: Gold Coast industry share of regional employment to February 2013

Source: DEEWR (2013)

The construction industry is not only a large employer, but is headed by an award winning, avant-garde group of developers, designers and builders who since the mid-1960s have created iconic residential towers, and the sprawling canal estates and suburbs of the region. The City's population is forecast to grow to 678,000 by 2020 and over 798,000 by 2031 (QTT 2013), requiring at least 143,000 more dwellings. The major growth areas indicated in Figure 2.4 are the Coomera-Pimpama and adjacent Upper Coomera districts. Helensvale, Nerang, Southport, Robina and the coastal strip are the major infill development areas indicated in Figure 2.13 B.

Supporting the building industry is a vast array of materials and component manufacturers and suppliers, clustered in seven main industrial areas and 12 extractive industry sites throughout the region. The city has accessible quarry sources of hard rock and coastal deposits of sand and gravel, to support the development industry (see Figure 2.4). These are mostly in the northern part of the region, which is convenient to the Coomera-Pimpama greenfield development district. The city construction supply chain is dependent on importation of materials from Brisbane, 100 km by the Pacific Motorway to the north, which has major port and railhead facilities. The railway to the Gold Coast is primarily for passenger travel, but could be expanded to handle freight in the future with track duplication, at least to the Yatala industrial district. However, the SEQ Regional Plan 2009-2031 (Queensland 2009c: 148) shows no program for such an extension to the freight network. This is considered to have been a major shortcoming in the planning and design of the modern Gold Coast rail system. Hence, the Gold Coast building industry is heavily dependent on efficient road transport logistics for most of its operations, highly dependent on the M1 motorway linking to Brisbane suppliers.

Stationary energy supply relies on external electricity and gas sources. There are currently no significant supplies of locally generated mains electricity from either conventional or renewable sources. All high voltage electricity is transmitted from the SEQ grid, based on coal fired power stations such as Swanbank west of Brisbane. Low voltage rooftop solar PV domestic installations are local operating electricity alternatives delivering surplus power into the mains grid. Point source solar PV supply is used to power isolated lights and telemetry equipment. There is an extensive natural and coal seam gas pipeline distribution network developing throughout the Gold Coast region, which serves the commercial, industrial and mainly domestic market. However, it cannot be relied upon in greenfield development areas and in any case would not be useful in building construction. The local mill in the north eastern sugarcane land generates 30 MW of power from sugar cane waste (bagasse). Several council owned plants generate 3 MW of total power from landfill and sewage methane. The stationary mains energy supply for construction is therefore widely available and reliable, but it is highly dependent on conventional fossil fuel based sources, apart from minor contributions from bagasse and methane.

4.1.5 Conclusions to intervening factors

The main alternative materials and sources of energy have been described, which may act as intervening factors mitigating the supply and use of oil and gas in the City of Gold Coast. Some of these are direct substitutes, while others have less embodied energy. The use of alternatives early in this century appears to be justified more on cost efficiency rather than on environmental grounds, although greenhouse gas mitigation is very important, as noted in Chapters 1 and 3. The reason is because in the South East Queensland context, the main substitutes involve the exploitation of coal seam gas, which could become increasingly important in mains electricity generation and in the local manufacture of petrochemical plastics and paints. Minor renewable energy sources are bagasse and bio-methane, plus domestic solar PV to lower operational LCA energy. In terms of the mitigation and adaptation terminology proposed in section 3.2.2, these factors have mitigating effects on the energy supply and gaseous fuels available at the Gold Coast. Alternative sustainable building materials and construction principles—including eco-efficiency, more durable materials, products and components to extend the life cycle of buildings—will have adaptive effects to increase the resilience of settlements to oil constraints. The relative importance of the intervening factors in land development and building construction is further analysed in the case studies and discussion in Chapter 5, which may further modify the Part 1 proposition.

4.2 Moderating factors in urban development

Having examined the intervening factors in the oil-related inputs stream of the conceptual framework, this section addresses the moderating factors in the planning-related social factors stream, highlighted in **Figure 4.4**. It includes relevant parts of the state and regional planning framework; key provisions of the current planning scheme for the City of Gold Coast; key elements of the Building Code of Australia and Queensland Development Code regulations; and planning reforms commenced in 2013.

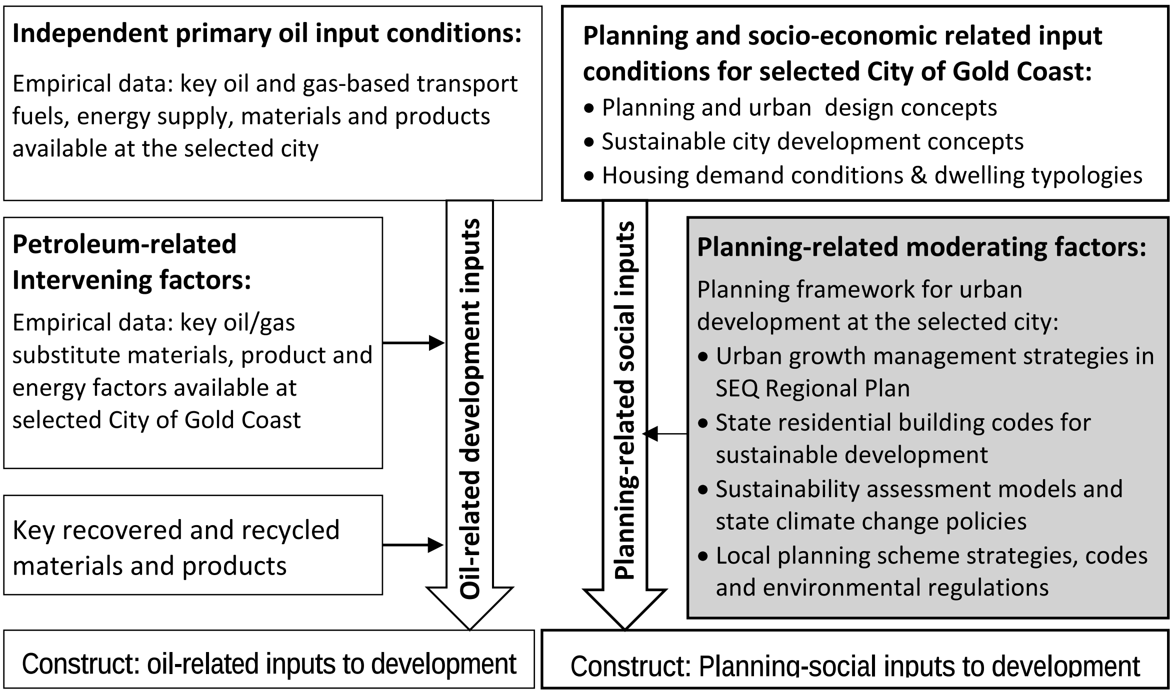


Figure 4.4: Conceptual framework highlighting moderating factors

Source: The author

4.2.1 Current state and regional planning framework

The current Queensland planning framework is under the *Sustainable Planning Act 2009* (SPA). South East Queensland (SEQ) is regulated by the 2009 SEQ Regional Plan and local government planning schemes made under the SPA and its similar precursor the *Integrated Planning Act 1997* (IPA). Queensland planning legislation underwent a significant shift in policy direction with the enactment of the performance based IPA, which introduced ecological sustainability as the overriding object of the Act. The Integrated Development Assessment System is the mechanism for assessable development approvals. The planning system reforms commenced in the IPA were refined in the SPA, which adopted the wider Qplan concept, including the line-of-sight planning framework in **Figure 4.5**. Qplan has been the key policy framework since 2009 for sustainable development, resource conservation, mitigating greenhouse emissions and adapting to climate change impacts from statewide to local level. The legislation and policies are categorised at the relevant level of application. The framework has been subject to a fundamental overhaul of the planning system by successive state governments elected since March 2012[20]. The current model is retained in this thesis to contrast with new planning directions still under development; the highlighted items are affected by the planning reforms. The SPA will be replaced by new planning legislation. The planning reforms are addressed in section 4.3 and in Appendix H in the CDROM.

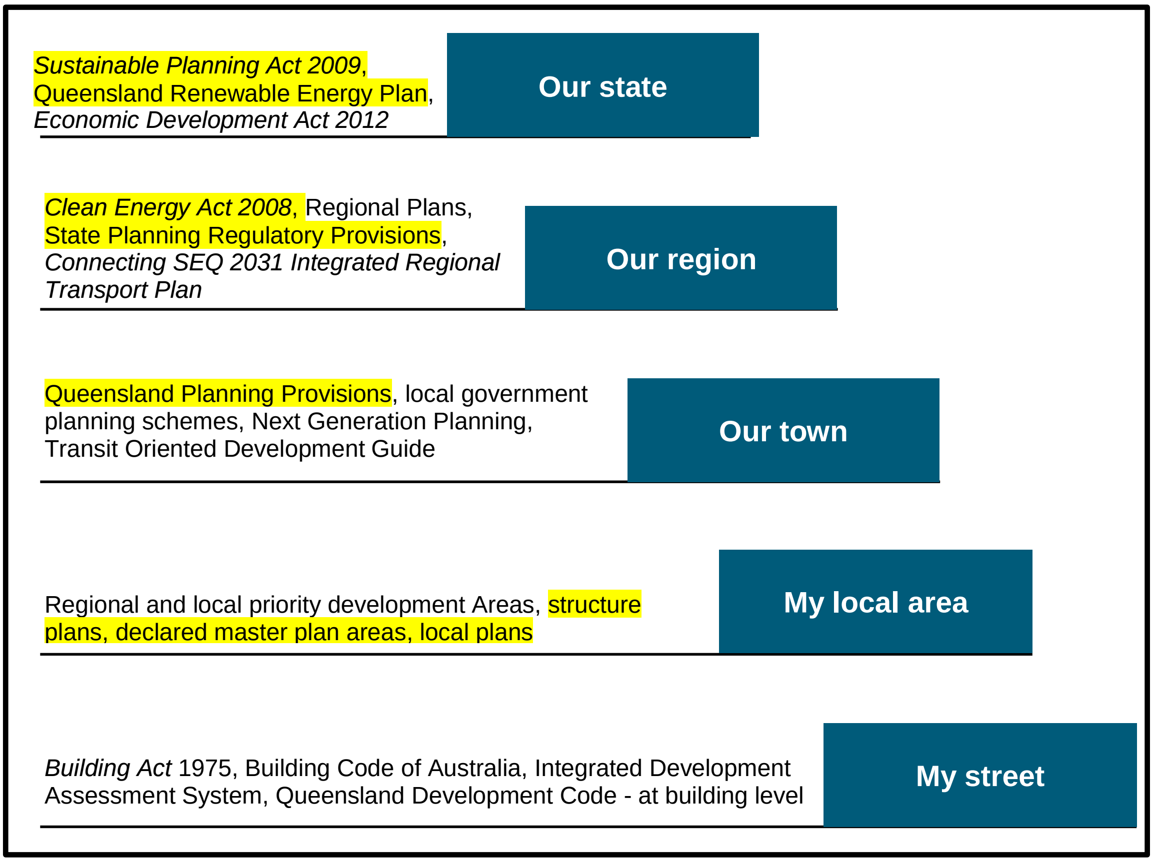


Figure 4.5: Qplan line-of-sight legislative and planning framework

Source: Modified from Queensland Government (2009c: 7)
Highlighted items are affected by the planning reforms

Section 5 of the SPA states that advancing the Act's purpose includes:

(b) ensuring the sustainable use of renewable natural resources and the prudent use of non-renewable natural resources by, for example, considering alternatives to the use of non-renewable natural resources;

(e) supplying infrastructure in a coordinated, efficient and orderly way, including encouraging urban development in areas where adequate infrastructure exists or can be provided efficiently;

(f) applying standards of amenity, conservation, energy, health and safety in the built environment that are cost-effective and for the public benefit.

[20] As noted in section 2.4.3 of chapter 2, a second change of state government occurred in early 2015 after completion of this thesis, reverting to a minority Australian Labor Party (ALP) government, which had developed the Qplan concept and the 2009 SEQ Regional Plan. The new government reversed major policy changes such as climate change, and at early 2016 is still in the process of gaining Parliamentary approval for new planning legislation to replace the SPA.

The SEQ region, as at 2014 comprised 12 local government areas totalling 22,900 km^2. The first SEQ Regional Plan 2005-2026 State Planning Regulatory Provisions introduced the Urban Footprint concept to redress the failure of previous SEQ planning schemes to constrain residential sprawl under earlier planning legislation. Prescriptive zoning controls were relaxed with the concept of 'material change of use' under the SPA that allowed more flexible changes to the residential urban form than the prior rezoning technique. The regional plan promoted compact urban forms within a defined urban footprint. In the SEQ Regional Plan 2009-2031 now under review, three of the desired regional outcomes (DROs) have been relevant to this research in relation to future urban form. They promote sustainable development in a compact structure, with an accessible integrated transport system supporting public and active modes:

> DRO1 - The region grows and changes in a sustainable manner—generating prosperity, maintaining and enhancing quality of life, minimising the use of resources, providing high levels of environmental protection, reducing greenhouse gas emissions and becoming resilient to natural hazards including the projected effects of climate change and oil supply vulnerability.
>
> DRO 8 - A compact urban structure of well-planned communities, supported by a network of accessible and convenient centres and transit corridors linking residential areas to employment locations establishes the context for achieving a consolidated urban settlement pattern.
>
> DRO12 - A connected and accessible region based on an integrated transport system that is planned and managed to support more compact urban growth and efficient travel; connect people, places, goods and services; and promote public transport use, walking and cycling. (Queensland 2009c: 39, 90, 139)

The SPA advances the evolution of the performance based planning concept started with the IPA, and a return to the requirement for strategic planning in the form of a strategic framework within standardised planning schemes. The SPA focus on strategic outcomes through an integrated framework of state, regional and local planning instruments gives clear expression to achieving the objectives of the SEQ Regional Plan for sustainable development within a compact urban form. Under the planning reforms 'new regional plans will focus only on those state issues that require regionally-specific policy direction to supplement the policy direction and associated guidance about state interests in a new single State Planning Policy' (DSDIP 2013c: 1). The implications of these and other aspects of planning reform are addressed in section 4.3.

4.2.2 Queensland Planning Provisions for new planning schemes

Current planning schemes are still based on the old IPA framework and are being reviewed to comply with standardised Queensland Planning Provisions (QPPs) under the SPA. The case studies for this research were all approved under the earlier IPA legislation. The statutory QPPs themselves have a new version 3 released in November

2013, but could be affected by the planning reforms (Queensland 2013b). The QPP3 aims to achieve a consistent format, zoning terminology and use definitions with standardised residential zones (with different names from QPP2) including:

- *Low density residential* - to provide for predominantly dwelling houses supported by community uses and small-scale services and facilities that cater for local residents
- *Low-medium density residential* - to provide for a range and mix of dwelling types including dwelling houses and multiple dwellings supported by community uses and small-scale services and facilities that cater for local residents
- *Medium density residential* - to provide for medium density multiple dwellings supported by community uses and small-scale services and facilities that cater for local residents
- *High density residential* - to provide for higher density multiple dwellings supported by community uses and small-scale services and facilities that cater for local residents.

(Queensland 2013b: Part 6-32-34)

None of the above zones promote mixed use development, which is restricted to designated Mixed Use zones (below). Some outcomes relevant to this research that are sought for the higher density residential zones are expressed in the following terms:

- Development encourages and facilitates urban consolidation and the efficient use of physical and social infrastructure.
- Development provides for an efficient land-use pattern that is well connected to other parts of the local government area.
- Development is designed to maximise energy efficiency, water conservation and public/active transport use.
- The scale and density of development facilitates an efficient land-use pattern and walkable neighbourhoods that are well connected to employment nodes, centres, open space and recreational areas, community services and education facilities.
- Non-residential uses may be supported where such uses provide for the day-to-day needs of the immediate residential community, do not detract from the residential amenity of the area and do not undermine the viability of nearby centres.

(Queensland 2013b: Part 6 - 33)

<u>Major centres</u> 'provide for a mix of uses and activities. It includes concentrations of higher order retail, commercial, offices, residential, administrative and health services, community, cultural and entertainment facilities and other uses capable of servicing a subregion in the planning scheme area'. Residential development and short-term accommodation 'is provided at an appropriate scale and integrates with and enhances the fabric of the centre'. Public open space areas including 'malls, plazas, parks and gardens' are to be provided (Queensland 2013b: Part 6 - 37).

<u>Mixed Use zones</u> provide for a mix of activities that may include business, retail, residential, tourist accommodation and associated services, service industry and low impact industrial uses (Queensland 2013b: Part 6 - 52).

<u>Precincts</u> may be used to provide more refined planning intent for specific areas. 'A precinct may vary the provisions (such as height, gross floor area and numbers of persons) for areas in the zone'. Provisions may provide for higher density in the precinct. (Queensland 2013b: Part 6 - 55).

The QPPs are supportive of flexible development of efficient infrastructure using sustainable practices to maximise energy efficiency (which should include embodied and operational energy). The QPPs promote a scale and density of development that facilitates an efficient land use pattern and walkable neighbourhoods, which could have a positive impact on transport of construction materials to the extent of local distribution and on workforce transport. However, if local plans promote large areas of low density residential with predominantly dwelling houses and small-scale facilities, without a conscious effort at urban consolidation, a compact form will not be achieved. Providing non-residential uses even in the higher density residential zones, only for the day-to-day needs of the immediate community, tends to limit mixed use development—unless it is in a major, district centre, or Mixed Use zone—so that commercial viability is not undermined. The compact urban form is therefore best achieved by increasing the area of high density development in centre type zones, which currently have limited potential value as primary moderating factors in residential development because of piecemeal *ad hoc* redevelopment policies. The current state polices to facilitate a more sustainable compact urban form would only be effective if the intended efficient land use pattern restricted new low density residential environments, categorised as Next Generation Suburban Neighbourhoods in the urban transect in Figure 2.5, in order to maximise transport energy efficiency.

4.2.3 Building Code of Australia and Queensland Development Code

The key oil and gas related inputs to urban residential development may be affected by the Building Code of Australia (BCA) and the Queensland Development Code (QDC) regulations. This section highlights the provisions relevant to the research.

Building Code of Australia

The BCA under the National Construction Code is the national technical document that sets the standards for building work in Australia. It is produced and maintained by the Australian Building Codes Board (ABCB) on behalf of the Australian Government and State and Territory Governments (ABCB 2010). The BCA has been given the status of building regulations by all States and Territories. The BCA contains technical provisions for the design and construction of buildings and other structures, covering such matters as structure, fire resistance, access and egress, services and equipment, and certain aspects of health and amenity. The BCA codes for building access effectively make lifts (elevators) mandatory in Class 2 residential buildings to meet the Premises Standards for disabled people. If the building parking is on ground or basement level, a lift or ramp is required to the first habitable level of sole occupancy units. The BCA has incorporated more energy efficiency requirements, including a minimum 6-star energy equivalence rating from 1 May 2010 for all new houses and townhouses and major renovations to such buildings (but not apartments):

a. The rating is determined by the design of the building's envelope, or its shell—i.e. roof, walls, windows and floors. For example, an extra star credit can be gained for a covered outdoor living area.
b. An energy equivalence rating does not take into consideration the fixtures and appliances of a house or townhouse, such as hot water systems, air conditioners, lighting and fridges. An extra star credit can be gained for a solar PV system.

Queensland Development Code

The Queensland Development Code (QDC) consolidates Queensland-specific building standards into a single document and covers Queensland matters outside the scope of, and in addition to, the BCA (Department of Housing and Public Works 2013). If there is an inconsistency between the BCA and the QDC, the QDC prevails. A local planning scheme cannot regulate the design of a building in so far as it conflicts with the scope of the Building Assessment Provisions (BAPs) (under BCA and/or QDC). Hence, a scheme cannot set requirements or extend the standards that determine how a building is to address energy efficient design. A planning scheme may, however, require matters outside the scope of the BAPs to be addressed. For example, a scheme can address the external appearance of a building by requiring the external form of the building to meet certain standards. A scheme can determine the orientation of land lots as part of a reconfiguration of lot application. The QDC addresses a limited range of building related sustainability issues in SEQ in sections MP 4.1 and MP 4.2 to ensure:

a. class 1 and class 2 buildings are energy and water efficient (including rainwater tanks)
b. air-conditioners installed in class 1-10 buildings are efficient
c. end of (bike) trip facilities are provided in major developments in designated areas.

In 2010 the QDC introduced the requirement for a sustainability declaration on the sale of a dwelling as an incentive to promote the energy and water efficiency features. In 2012 the new state government removed this requirement and the mandatory installation of rainwater tanks (unless approved by the Minister upon application by a local government), as an unnecessary impost on the housing market and building industry. Such changes geared to assist the industry are considered in this thesis to be a retrograde step in the long term improvement in sustainability of Queensland housing.

The new BCA requirements are applicable to new work and renovations after November 2010. The energy efficiency provisions link to the BCA for star ratings and indicate acceptable solutions. These requirements were not applicable to construction commenced prior to 2010 and therefore did not modify the oil and gas inputs to residential buildings involved in the case study research. However, all development commenced after 2010 is positively affected by the more stringent BCA and QDC standards for energy efficiency. Future residential development is required to be more responsive to conservation of embodied and operational energy, thereby reducing oil and gas inputs to meet rising energy efficiency standards. While this contributes to reducing energy demand, it may not lead to broader sustainable outcomes.

These regulations will better facilitate adaptation to the oil-constrained future directly in relation to energy inputs. Yet, the regulations will only have an indirect influence with respect to oil and gas feedstock inputs into land development and building construction materials. The BCA codes for lifts could constrain medium density residential buildings (between 4 and 8 storeys) economically. In summary there is no impediment in the BCA or the QDC as moderating factors to advancing the conceptual framework to the next stage of research.

4.2.4 Sustainability guidance and related government policies

This section considers how the sustainability guides and related government policies might be a moderating factor in residential construction. Section 3.2 analyses the relationship between oil consumption and climate change as twin global problems, particularly in the Australian policy context. Section 3.3.2 shows that the global warming impacts are evenly spread across most construction materials. The dominant contributor to global warming is CO_2, which is the focus of most of the efforts to transfer to renewable energy sources and to improve the environmental sustainability of building materials. Numerous guidelines and rating systems have been put forward, specific to buildings, to assess construction sustainability across a range of factors (e.g. Woolley et al. 1997; Brandon & Lombardi 2005; Roaf 2007). In the Australian residential assessment context, these systems include BASIX (New South Wales Government 2004); the Green Star rating (Green Building Council of Australia 2009); and the Nationwide House Energy Rating Scheme (NatHERS) (Australian Government Department of Climate Change and Energy Efficiency 2012). NatHERS includes AccuRate Sustainability (geared to CO_2 reduction) and BERS House Energy Rating Scheme software tools. While these rating schemes are mostly focused on CO_2 reduction, they have the equally desirable effect of reducing oil and gas demand, with concomitant economic and environmental benefits. The LEED and BREEAM rating systems noted in section 1.1 are useful tools, but are not universally relevant to Australian circumstances.

Assessing or rating the sustainability of groups of buildings at a precinct or neighbourhood scale is a more recent development. Examples include the Western Australia Planning Commission (WAPC) *Liveable Neighbourhoods* (WAPC 2011); Green Building Council of Australia (2010b) *Green Star Communities*; PrecinX™ precinct sustainability tool (New South Wales Government 2010); Urban Development Institute of Australia (2011) *Envirodevelopment* branding; and the VicUrban Sustainable Community Rating (VicUrban 2012). All these wider scale rating systems are voluntary in application, yet provide valuable design guidance to reduce energy input and CO_2.

Good planning and design of cities can successfully help to reduce greenhouse gas (GHG) emissions while maintaining a high standard of living and meeting wider sustainability goals (David 2009). The 2009 SEQ Regional Plan recognises that planning of the spatial pattern and density of urban areas and associated transport infrastructure can reduce the need to travel, influence transport modes, and result in achieving lower GHG emissions. For example, providing closely integrated residential, employment, commercial and educational developments in new communities can help reduce the need for travel and therefore transport related GHG emissions. By ensuring such developments are energy efficient and well located with good access to active and public transport, the Queensland planning system supports communities in South East Queensland to adjust to a low-carbon economy and new patterns of behaviour and energy use. These policies directly assist in adapting to oil depletion at precinct scale.

However, the development and building industry is an important driver that is also a barrier to change, because housing types and construction form are largely dictated by the investment market. Despite the strategic directions, the private land and building industry is slow to change from the predominant detached housing model in most greenfield suburban development areas, making a transition to a more compact urban form problematic. This business as usual approach is evident in several ways:

a. Real estate promotions, newspapers and building magazines promoting new construction tend to be biased towards large detached family houses in greenfield locations, or expensive inner city apartments.
b. Builder display villages also are biased towards large detached houses, although some of the promotional pictorial material does offer smaller designs and buildings suitable for small or narrow lots. Small display houses are only infrequently available for prospective home makers to assess their liveability factors relative to price advantages on the ground.
c. The Queensland Master Builders Association (MBA) housing awards are based on nine price range categories for individual houses. The winners tend towards large detached houses as being 'value-for-money'. There are also two price categories for small lot housing, two price categories for low rise multi-residential housing, and just a single category for medium rise multi-residential housing (3 storeys).
d. The MBA and Housing Industry Association are forward looking to use 'green building' design. In contrast, investors in greenfield developments look for cheap rental houses bought off the plan, with little or no voluntary incentive to incorporate energy or sustainability features that reduce operating costs (Norimi V. pers. comm. 2012).
e. There is little emphasis on housing which is adaptable to a range of changing lifestyles, aging in place, sharing of accommodation, or home based business.

These property and building industry drivers are therefore potential barriers to change. The related planning system also becomes a barrier unless sufficient strategic information is released to guide both public and private decision making about future oil constraints. One public example of this is in the 2009 SEQ Regional Plan that seeks to implement the Transit Oriented Development (TOD) Guideline released in 2010 (Queensland 2010b). An introductory discussion on TOD issues is provided below.

The TOD guide links to another SEQ Regional Plan policy—*Connecting SEQ 2031: an integrated regional transport plan for South East Queensland* (Queensland 2011). This policy promotes a vision of 'urban villages' with a 15-minute walking radius, linked to other urban areas by priority transit corridors. It sets ambitious targets for a swing to public and active transport to change the way the region moves during the next 20 years. It expects to reduce greenhouse gas emissions in three ways by:

1. increasing the mode share of active transport from 10% of all trips in the region in 2006, to 20% by 2031
2. increasing the mode share of public transport from 7% in 2006, to 14% in 2031
3. reducing the mode share of private motor cars by about one fifth. This would mean the share of trips taken by private motor vehicles would decline from 83% in 2006 to 66% in 2031. (Queensland 2011: 4)

While the targets in the SEQ integrated transport plan policies look impressive, they are aspirational, and in fact disguise a forecast *increase* in private motor vehicle movements by 30 per cent, from 7.64 to 9.9 million trips per day, by 2031 (2011: 24). The transport network is intended to become resilient to the vulnerability of reduced oil supply, rising oil prices and climate change impacts; but it has no detailed plans. The state government also has a draft oil vulnerability management strategy, which has not been released, beyond the 2007 taskforce report (Queensland Parliament 2007), which is discussed in section 3.2.1. The subsequent *Oil Vulnerability Strategy/ Action Plan for Queensland research paper* (Waller 2008) suggests mitigation strategies to reduce oil-based fuel use, 'delivered primarily via sharply increased fuel efficiency and fuel switching' (Waller 2008: 6). Even with these strategies, the total fuel demand in Queensland is projected to increase by 50 per cent by 2030, from some 7,300ML to over 11,000ML' (Waller 2008: 23).

Transit oriented development

The TOD concept potentially plays an important role in supporting the use of more sustainable modes of transport, including public transport, walking and cycling, and reduces the distances people must travel to access goods, services and employment opportunities. It should also help address traffic congestion, energy conservation, mitigation of climate change, and air-quality improvement. However, much of the implementation of TOD has not fulfilled the broad expectations attributed to it, both in South East Queensland and elsewhere (Dittmar & Ohland 2004; Curtis 2012: 84). Curtis has written extensively on TOD, drawing on examples in Perth, Western Australia and overseas. She contends that 'Perth has been one of the most deliberate attempts worldwide to move from car-dependent development patterns to transit-oriented development' since the TOD policy was introduced in 1988 (Curtis 2012: 85). The Perth policy focuses on transit precincts based on all rail station nodes. Yet her 2012 survey of town planning and institutional arrangements revealed that the intended higher residential densities and employment density generally have not been achieved around either district or inner urban new stations (Curtis 2012: 91). Curtis notes that the intended high TOD densities at around 15 dwellings per hectare are low by European standards, and fall short of the 25 dwelling per hectare indicated in the 2005 state TOD policy (Curtis 2012: 90). She suggests that 'further research is needed in order to understand the interplay between the local government, property market, development industry and community in relation to the implementation of TOD using the conventional planning approach' (Curtis 2012: 96). This aspect is also relevant to the SEQ context where the property industry exerts a strong influence on developers and the market. Bajracharya and Khan (2006: 43) agree that site amalgamation is a major problem for infill TOD and a taskforce style intervention is needed to gain support, select and develop sites. A successful Perth model to implement TOD is to use redevelopment authorities (RDAs) where the RDA becomes the developer, as in the case of the Subiaco TOD precinct where an additional 1,000 dwellings units and 70,000 square meters of commercial floor space developed by 2005 (Howe *et al.* 2009). Yet even Subiaco is a generally low rise development and under-achieves intended density.

The whole basis of this style of TOD is questionable in relation to the broader aspirations expressed in this thesis for larger public and active transport *mobility* precincts. In an oil-constrained future, this thesis contends that densities need to be increased in all areas to support not just TOD, but an inverted term development oriented transit (DOT) used by Mepham to describe a planner's focus on the opportunities for transit to integrate with the built environment and community accessibility (Mepham 2013: 24). Even this terminology is inadequate for the future, because of the whole connotation of *transit* to and from precincts, rather than *mobility* within much larger precincts. This distinction will become more evident over time with oil depletion. Hence the thesis contends that a different term *public-active mobility oriented development* (P-AMOD) is more useful to describe the city of the future.

Queensland Renewable Energy Plan

The Queensland Renewable Energy Plan (QREP), relaunched in February 2012 prior to the state election, outlined a comprehensive roadmap for expanding the renewable energy sector in Queensland. It provided a framework to increase the proportion of the state's renewable electricity capacity from Queensland based sources. The plan aimed to reduce GHG emissions by more than 40 million tonnes. A key initiative of the QREP was to implement the Clean Energy Communities (CEC) initiative.

Since the April 2012 election, the state government stepped back from this policy, and issued a discussion paper in 2013 for a 30 year electricity strategy. The aim of the strategy is 'to focus not only on the issues of today, but to take a horizon view of what opportunities and challenges lie ahead for the sector in the decades to come' (Queensland 2013c: i). While climate change is a recognised driver of change, the thrust of the paper is to limit consumer cost increases and support economic growth.

Curiously, the paper acknowledges that in the next 30 years ‘the development of a $50 billion liquid natural gas export industry will create a fundamental shift in the Queensland economy, and add considerable demand on our electricity system’ (Queensland 2013c: 2). The LNG and electricity industries will combine to increase CO_2 emissions. This suggests there is no state policy for climate change mitigation and any moderating effect of such policies is very weak in relation to the construction industry.

Analysis Conclusions

Various codes and rating systems apply to the City of Gold Coast relating to sustainable development assessment in the context of climate change mitigation. The building ratings for energy efficiency are mandatory, as noted in Section 4.2.4. The voluntary sustainability rating principles have desirable effects of reducing oil and gas demand, with concomitant economic and environmental benefits. The current Queensland planning system supports communities in South East Queensland to adjust to a low-carbon economy and new patterns of behaviour and energy use. The policy mechanisms relevant to the Gold Coast are the SEQ Regional Plan, the TOD Guideline, and the related *Connecting SEQ 2031* plan. These policies set targets that look impressive, but they are aspirational, and in fact disguise a forecast *increase* in private motor vehicle movements by an overall 30 per cent from 7.64 to 9.9 million trips per day by 2031. The polycentric nature of the Gold Coast urban form exacerbates the number of private motor vehicle movements. Hence while the broad urban form and transport related policies aim to reduce greenhouse gas emissions as a strong moderating factor; the practical application is highly dependent on the planning scheme strategic framework guiding the development industry in the choice of infill or greenfield housing. This thesis contends that a different term public-active mobility oriented development is more useful to describe the type of urban development in an oil-constrained future. The changes in state governments since March 2012 have seen a major ongoing overhaul of the planning framework and climate change related policies. As at late 2015, there was no clear guidance to the development industry or this thesis research. The planning framework affects all development in Queensland and is relevant to the Gold Coast planning scheme, which is discussed in the next section.

4.2.5 Gold Coast planning scheme

The 2003 Gold Coast City Council (GCCC) *Our Living City* planning scheme was the first IPA scheme for a major metropolitan area in SEQ (GCCC 2003). The scheme was under review as the draft *Bold Future Planning Scheme* and submitted in February 2012 by the GCCC to the then Department of State Development, Infrastructure and Planning for the state interest check. A change of council elected representatives in the April 2012 elections caused the draft plan to be withdrawn and it had not been completed as at late 2015, because of the ongoing state planning reform agenda. Further discussion about the implications for this thesis research is in section 4.3.3 on planning reform. The *Bold Future Planning Scheme* strategic framework advocates a city 'shaped by clever design' comprising an urban settlement pattern of activity centres, industry and business areas, transit supportive urban neighbourhoods, suburban neighbourhoods and new communities[21]. The definitions of the draft scheme relevant to this research are summarised in **Table 4.1.**

Table 4.1: Gold Coast Planning Scheme development and building definitions

PLANNING TERMS	PLANNING SCHEME PROVISIONS
Dwellings and building terms	
Dual occupancy	Premises containing two dwellings on one lot (whether or not attached) for separate households.
Multiple dwelling (2003 scheme Apartment)	Premises which contains three or more dwellings where the use is primarily residential. Includes apartments, flats, units, townhouses.
Attached dwelling and medium density detached dwelling	A dwelling attached to or touching another dwelling. This is a more specific definition than 'dwelling'. [This may include duplex dwellings, row houses and townhouses.]
Dwelling house	A residential use of premises for one household which contains a single dwelling.
Building height	In metres, the vertical distance between the ground level and the highest point of the building roof (apex) or parapet at any point but not including non-load bearing antenna, aerial, chimney, flagpole or the like. In storeys, the number of storeys above ground level.
Storey (Note: the Building Code of Australia also excludes a mezzanine)	That space within a building which is situated between the floor of one level and the floor of the next level above, or if there is no level above, the highest point of any impermeable ceiling above. The term includes any useable space on the roof area covered by impermeable material. A basement does not constitute a storey for the purposes of calculating the number of storeys.
Low rise building	Any building with a height not exceeding four storeys above mean ground level. (The 2012 draft planning scheme proposes a building height up to 8.5 metres; two storeys with option for a partial third storey if within 8 metres height.)
Medium rise building	(The 2012 draft planning scheme proposes a building height exceeding 8.5 metres to 35 metres; between three and eight storeys above ground level.)
High rise building (2012 scheme – tall buildings)	Any building with a height of five storeys or more above mean ground level. (The 2012 draft planning scheme proposes a building height above eight storeys.)
Use definitions	
Active and public transport supportive use	A use that, by its nature, encourages travel by active and public transport over private motor vehicles, or attracts users that commonly travel by active or public transport.
Affordable housing	Housing that is appropriate to the needs of households with low to moderate incomes.
Compact and efficient urban form	Occurs within activity centres and transit supportive urban neighbourhoods (including the light rail urban renewal area), to support the best use of existing or planned public transport infrastructure.
Home based business	A dwelling used for a business activity where subordinate to the residential use. Includes a home office; excludes a shop or office.
Infill development	Development in existing developed areas usually involving the use of vacant land or the replacement or removal of existing uses to allow for new uses.
Medium and high intensity housing	Occurs within activity centres and transit supportive urban neighbourhoods in a form, size and intensity that are appropriate for each particular locality.

[21] After more than two years in the making, the new Gold Coast *City Plan* commenced on 2 February 2016 (GCCC 2016). City Plan is strongly informed by elements of the *Bold Future Planning Scheme*, hence the information is still considered to be relevant to this thesis. In contrast to the draft scheme: *Urban neighbourhoods* are compact, pedestrian-friendly, offer housing choice and high amenity and provide access to facilities, services, public transport, employment and essential infrastructure. They are generally located near high frequency public transport corridors served by light rail or rapid bus. *Suburban neighbourhoods* are places for low intensity, low-rise, predominantly detached housing in a generous landscaped setting that retains and enhances local character and amenity by maintaining existing scale, building height and intensity despite its proximity to public transport or other services.

PLANNING TERMS	PLANNING SCHEME PROVISIONS
Suburban Neighbourhood areas	Extensive low-intensity residential environments with a focus on retaining and enhancing neighbourhood character and amenity. (Draft Part 3, p. 36)
Transit oriented development	Mixed use residential and employment areas, designed to maximise access to public transport through higher density development and pedestrian-friendly street environments.
Transit supportive urban neighbourhoods	• are compact and pedestrian-friendly neighbourhoods that offer many housing choices and support affordable living opportunities by providing easy access to a full range of facilities, goods, services and employment opportunities; • take different forms, from small pockets of detached housing provided on smaller lots within an urban setting, to areas where medium intensity and medium scale buildings are dominant and to higher-intensity places supported by high-rise buildings. (Draft Part 3, p. 38)
Walking catchment	The area of land that is within walking distance, equivalent to the distance that can be covered in about 10 minutes comfortable walk time, (within 800 metres distance along a walkable route) from a particular location.
Residential density	Residential density is determined on overlay maps for particular areas:
Low density res. LDR1	Up to 12.5 dwellings per net hectare (1 dwelling/800m^2).
Low density res. LDR2	Up to 16.6 dwellings per net hectare (1 dwelling/600m^2).
Residential density RD1	Up to 25 dwellings per net hectare (one dwelling per 400m^2 of site area).
Residential density RD2	Up to 33 dwellings per net hectare (one dwelling per 300m^2 of site area).
Residential density RD3	Up to 40 dwellings per net hectare (one dwelling per 250m^2 of site area).
Residential density RD4	Up to 50 dwellings per net hectare (one dwelling 200m^2 of site area).
Residential density RD4A	Up to 66 dwellings per net hectare (1 dwelling/150m^2)
Residential density RD5	One bedroom per 50m^2 of net site area (up to 200 bedrooms per net hectare).
Residential density RD6	One bedroom per 33m^2 of net site area (up to 300 bedrooms per net hectare).
Residential density RD7	One bedroom per 25m^2 of net site area (up to 400 bedrooms per net hectare).
Residential density RD8	One bedroom per 13m^2 of net site area (up to 769 bedrooms per net hectare).
Gross Floor Area (GFA)	The total floor area of all storeys of the building (measured from the outside of the external walls and the centre of any common walls of the building), other than areas used for: • building services, plant and equipment; • access between levels; • a ground floor public lobby; • a public mall; • parking, loading and manoeuvring of vehicles; • unenclosed private balconies, whether roofed or not.

Source: Modified from *Bold Future Planning Scheme* draft planning scheme (GCCC 2012)

Application to the historic suburb of Labrador

The (re)development of transit supportive urban neighbourhoods is of particular interest to this research (GCCC 2012: Part 3 p.38). These areas are to be accessible by some form of public transport service within a 400 metre walking distance. Some are within or connected to the light rail urban renewal area shown in Inset B of Figure 2.13. They may be older inner suburbs close to activity centres, pockets of small lot housing, or parts of new communities. The draft zone mapping did not separately identify such areas, so the possible extent is unknown. The only indication is in the delineation of Low-medium, Medium and High density residential zones (in QPP3), which may align with the urban transect in Figure 2.5; but do so in practice only in discrete areas.

Figure 4.6 shows an example in the late-1800s Broadwater suburb of Labrador just north of the Southport CBD (Figures 2.13B, 4.13), as a settlement pattern that has been gentrifying since the 1980s. The area has good arterial road and bus route connections to the CBD area to fit the description of a transit supportive urban neighbourhood.

Figure 4.7 shows the population density in persons per ha in 2011 for the Labrador transect shown in Figure 4.6, based on ABS census data, to indicate the density in an older inner suburb. The High rise-high density (RD6) towers at the Broadwater shore gradate towards townhouses and cottages in the west. The area also has aged people's homes around Muir Street that increase the net density; however, parks and a foreshore park (Figure 4.6) distort the picture. Hence although the lot sizes are smaller towards the east, the actual density does not achieve even RD2 (33 dw/ha) over the two lower density transect zones. The tower precinct fails to reach even RD5. Nevertheless this area would be an obvious candidate for adaptive oil depletion strategies as an inner urban area. This area is a potential candidate for detailed application of transformative sustainable development principles that will be demonstrated in section 8.3 of chapter 8.

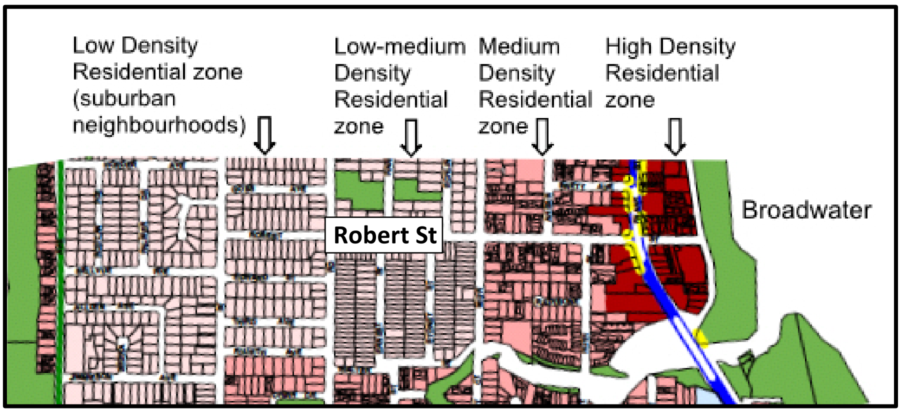


Figure 4.6: Typical discrete urban transect for Labrador, Gold Coast

Source: Modified Gold Coast draft planning scheme map 23 with permission (GCCC 2012)

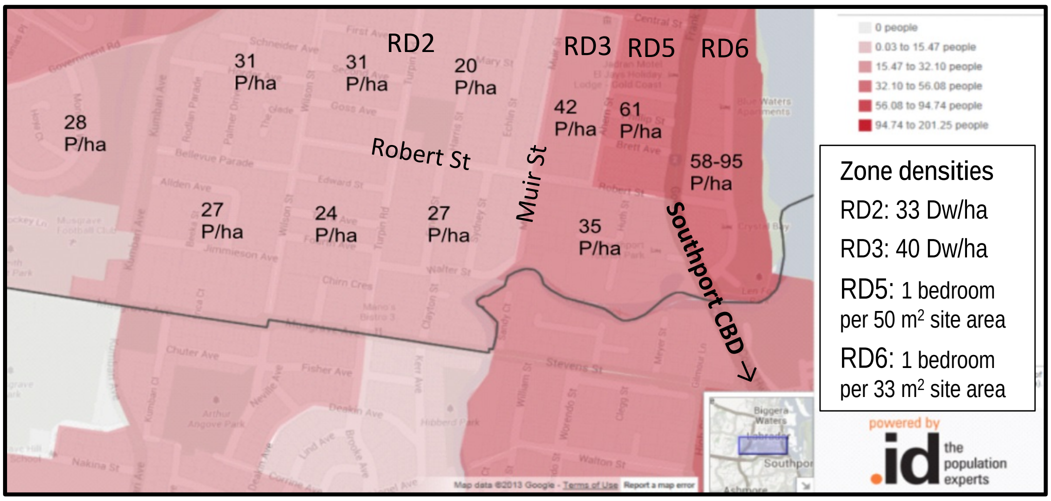


Figure 4.7: Labrador urban transect showing population density (persons/ha)

Source: modified from GCCC social atlas (Google 2013 base) (GCCC 2013)

The city population is forecast by Queensland Treasury and Trade (2013) to continue growing at 1.9 per cent, rising from 513,954 in 2011 to nearly 800,000 by 2031. Medium and high intensity housing is expected in the draft planning scheme to occur within activity centres and transit supportive urban neighbourhoods 'in a form, size and intensity that is appropriate for each particular locality'. Fortunately, apartment living is an accepted feature of the Gold Coast coastal strip, partly reflective of low occupancy rates (see Appendix C). This makes such housing more viable. An extract of the GCCC community profile-social atlas at **Figure 4.8** shows that in 2011 43 per cent of all dwellings at the Gold Coast were medium – high density, compared to 22 per cent in Brisbane; with a corresponding decrease in the proportion of detached houses (GCCC 2013b). However, the existing activity centres have not been well integrated with medium-high density accommodation and a major redevelopment program would be needed to achieve the intent of the plan for the city. The draft plan acknowledges that the suburban neighbourhood areas will remain 'extensively low-intensity residential environments with a focus on retaining and enhancing neighbourhood character' (GCCC 2012: Part 3 p.36). These traditional residential areas dominate the city, so are vulnerable to the future oil depletion shocks illustrated in the yellow and red zones of the VAMPIRE model in Figure 3.1 of chapter 3.

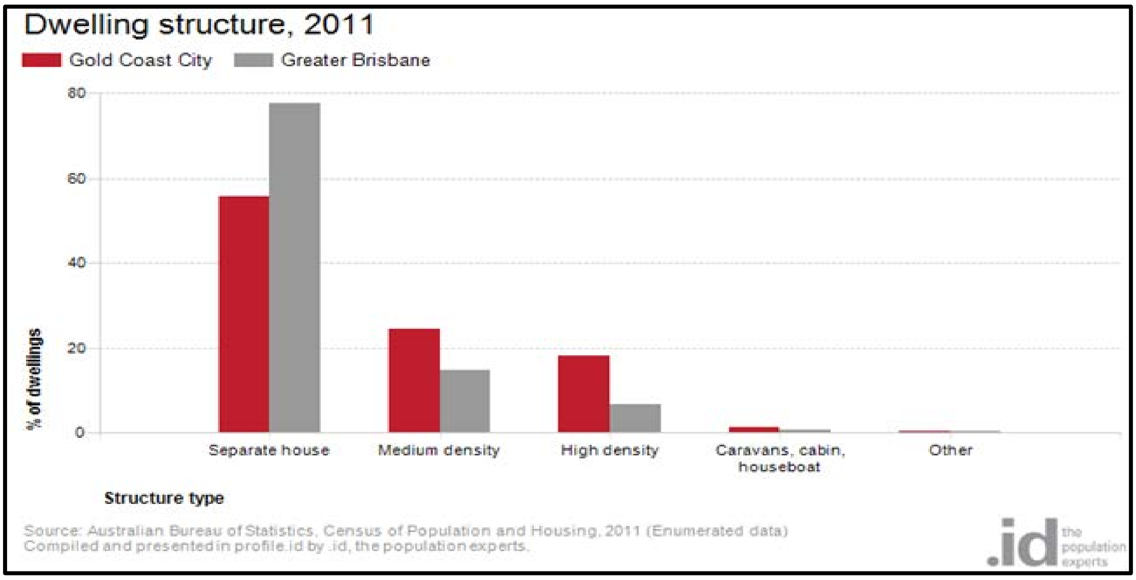


Figure 4.8: Comparison of dwelling types for Gold Coast and Brisbane in 2011

Source: GCCC social atlas (GCCC 2013b)

Application to suburban greenfield development area at Coomera

The strategic framework plans for 'new communities' on the city's remaining supply of greenfield land, such as in the Coomera district shown in Inset A in Figure 2.13. New development in Coomera is intended to be developed as suburban and transit supportive urban neighbourhoods around the Coomera Principal Activity Centre (PAC). However, current housing close to the PAC is more of the same low density, even though new communities aim to achieve a minimum yield of between 15 to 25 dwellings per net hectare. Case study A detached house is in this district. These areas are potentially vulnerable to oil depletion shocks, even with a focus on home based businesses, unless better integrated with the Next Generation Planning principles discussed in section 2.2.3. The strategic framework concepts are considered to be aspirational goals that will be highlighted by the outcomes of this research.

The draft scheme proposed implementation of the Mixed Use zone differs from the QPP3 intention, because it envisages residential development as a supporting activity to the primary function of the retail and commercial land uses that are not typically found within activity centres network. Residential uses are to be located above the ground floor and not exceed 75 per cent cite cover and building heights are not to exceed 12.5m [effectively about 4 storeys] (GCCC 2012: part 6.2.20 pp. 1-2). Hence the intention to use the Mixed Use zone, as defined in section 4.2.2, may *appear* to achieve adaption towards transit supportive neighbourhoods, but its scope to do so is limited by the council priority settings on development within such zones.

Analysis Conclusions

The draft 2012 Gold Coast planning scheme strategic intentions are generally supportive of compact transit supportive urban neighbourhoods. The QPPs require flexible development of efficient infrastructure using sustainable practices to maximise energy efficiency (which should include embodied and operational energy). Energy efficient subdivisions and buildings would reduce total life cycle energy requirements. The land use and building definitions provide a description of building types that can align with the case studies and the analysis of the urban density of the cases. The case studies have been designed and constructed under the 2003 planning scheme, to meet the criteria in section 2.3 of Appendix A, that they are internally consistent in relation to planning scheme provisions. The draft planning scheme does not substantively alter the criteria. No theoretical barriers to future sustainable development and building techniques have been identified in the current planning scheme review. The draft strategic framework in fact espouses the next generation planning principles discussed in section 2.2.3. Inner urban areas such as Labrador noted above would be obvious candidates for adaptive oil depletion strategies. The draft scheme generally complies with the requirements of the QPP3 criteria outlined in section 4.2.2. However, the strategic residential concepts related to greenfield development in areas such as Coomera are considered to be aspirational goals. They will need much detailed planning analysis in both existing suburbs and newly developing communities, to be relevant in adapting residential development to an oil-constrained future. Nevertheless, the achievement of these goals is highly relevant to this research. In summary there is no impediment in the QPPs or in the Gold Coast planning scheme as moderating factors to advancing the conceptual framework to the next stage of research.

4.2.6 Conclusions about current moderating factors

The discussion on the current moderating factors introduces a broad range of state legislation, strategic planning related policies and planning scheme codes. The state and local government planning policies and building codes control urban development in a contingent way and influence application of the independent urban planning and building design theoretical concepts. In the Queensland planning framework, the controls are necessary pre-conditions for any urban development to occur. The current SPA aims to ensure the sustainable use of renewable natural resources and the prudent use of non-renewable natural resources by, for example, considering suitable alternatives. The SEQ Regional Plan is fully supportive of energy efficient and innovative residential development in a compact urban form, which encourages higher density and reduces the use of resources. These controls affect the planning and design of all urban residential development in the context of the representative building typology devised for this thesis research. Even self-assessable detached houses must comply with the relevant zoning and constraint (overlay) codes. The draft Gold Coast strategic framework espouses the Next Generation Planning principles. In the Gold Coast context, inner urban areas such as Labrador near the Southport CBD would be obvious candidates for adaptive oil depletion strategies. The 2012 draft planning scheme generally complies with the requirements of the Queensland Planning Provisions criteria outlined in section 4.2.2. However, the strategic residential concepts related to greenfield development in areas such as Coomera are considered to be aspirational goals. They need much detailed planning in both existing suburbs and newly developing communities, to adapt residential development to an oil-constrained future. Nevertheless, the achievement of these goals is highly relevant to this research.

The energy efficiency provisions of the Queensland Development Code (QDC), linked to the Building Code of Australia (BCA), require star ratings and indicate acceptable solutions for residential development. None of these requirements were applicable to construction commenced prior to 2010 and therefore did not modify the oil and gas inputs to residential buildings involved in the case study research. However, all development commenced after 2010 is positively affected by the more stringent BCA and QDC standards for energy efficiency. Various codes and rating systems apply in the Gold Coast context to sustainable development assessment, but mainly in the context of energy efficiency. The voluntary sustainability rating principles have desirable effects of reducing oil and gas demand, with concomitant economic and environmental benefits. The adaptation strategies necessary to increase resilience would adopt planning outcomes for the urban form that anticipate changes in oil supply and cope with the consequences.

How these elements of the moderating factors fit together is schematically shown in **Figure 4.9.** It indicates how the elements nest into the current legislative planning framework. The hatched oval shows that the planning schemes are the integrating statutory planning measures in the framework, which may affect development at the local scale to achieve a compact urban form. The four main drivers discussed above are indicated on the right-hand side.

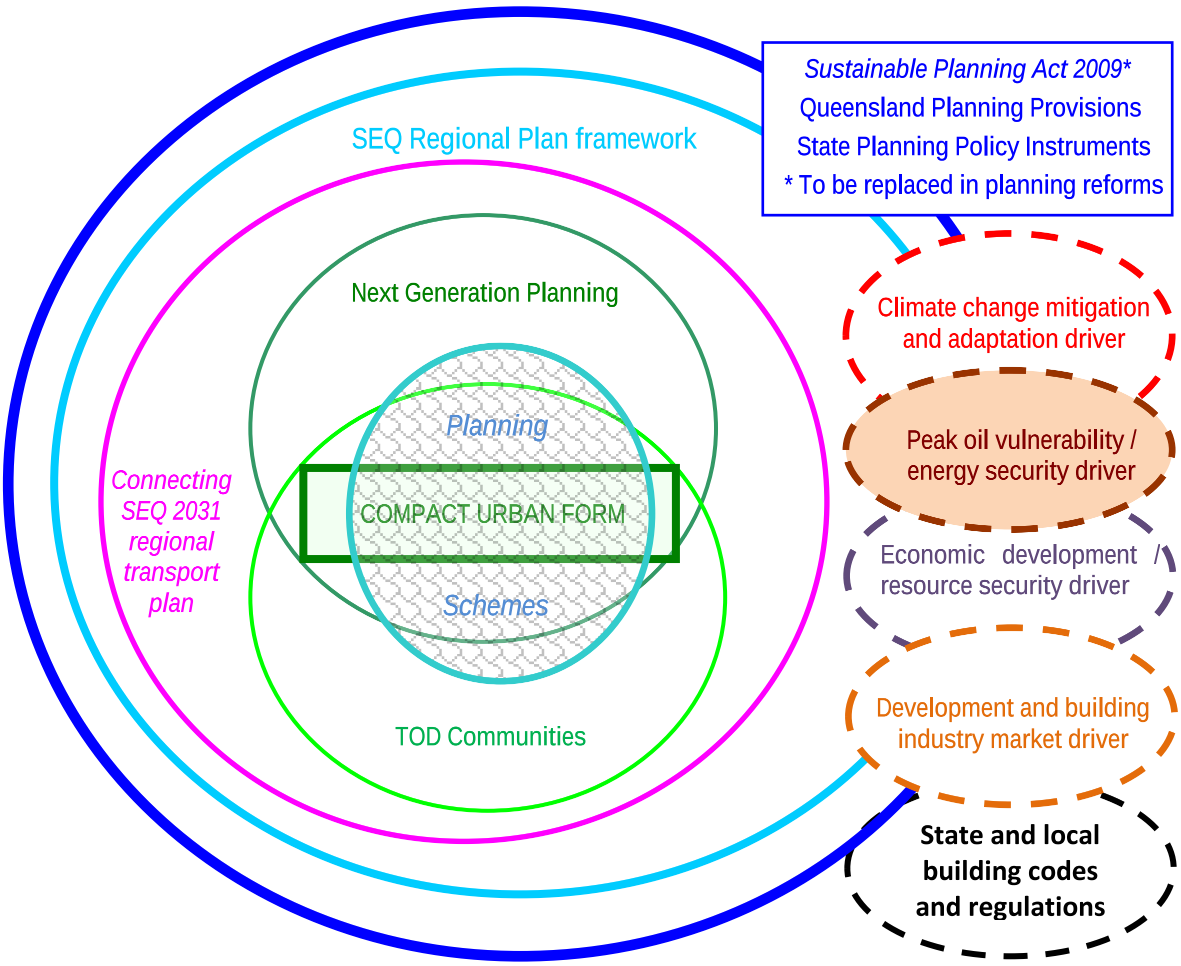


Figure 4.9: Planning framework moderating factors schematic diagram

Source: The author

Table 4.2 summarises the main effects of the multiple moderating factors on the planning and design of residential development in the City of Gold Coast context. A simple ordinal scale is adopted, because the qualitative characteristics are not amenable to a statistical test. The scale indicates the extent of negative or positive changes anticipated in the moderating factors to have adaptation effects.

It is concluded that while the current strategic planning tools have a potential beneficial, but not mandatory, influence on the forms of urban development, the future is uncertain. A change in state government in March 2012 initiated a major ongoing overhaul of the planning framework and climate change related policies, as noted in section 4.2.1. By late-2015 there was yet no draft planning legislation, no updated SEQ Regional Plan, and no clear state policy for climate change mitigation that would guide local government, or provide guidance to this thesis research.[22] The planning reform that affects all development in Queensland and is relevant to the Gold Coast planning scheme is discussed in the next section.

[22] These conclusions equally apply in relation to the successive change of state government in 2015.

Table 4.2: Summary of main effects of moderating factors

Scale: Negative = currently adverse effects; 0 = neutral or unresolved effects; +1 = potentially beneficial effects; +2 = expected beneficial effects; +3 = expected highly beneficial effects.

ELEMENT	NEGATIVE	0	+1	+2	+3
Sustainable Planning Act 2009 (SPA), to be replaced by new state planning legislation	Potentially less sustainability orientation		SPA is under review (see section 4.3)	Aspirational aims/ objectives to support 4 pillars economy	Simplification of development assessment process
SEQ Regional Plan 2009-2031 Desired Regional Outcomes and policies :	SEQ Regional Plan is under review and may be weakened in oil-related issue			Aspirational aims/ & limited policies dependent on planning scheme outcomes	Fully supportive of higher density energy efficient and compact urban form
- Transit Oriented Development			Voluntary guide for industry	Best practice is promoted	Fully supportive of compact form
- Integrated Regional Transport Plan policies and targets	Forecast 30% increase in car trips to 2031		Urban village concept in older suburbs	Aspirational aims /targets depend on funding	Active and public transport improvements
Next Generation Planning best practice guide	Urban transect still shows outer suburbs as a desirable form		Voluntary guidance planning codes only	Aspirational form codes and land subdivision/road design guides	'New urbanism' principles and compact urban form
Qld Planning Provisions:	Standardised provisions can slow innovation		Standardised provisions as a consistent planning guide	New strategic framework requirements for local government	Advocates efficient land use pattern
Building Code of Australia Qld Development Code	Detached house self-assessable		QDC MP 4.1, MP4.2 energy codes	Sustainability siting code under development	5/6 star ratings required under BCA codes
Sustainable assessment :	QDC cancelled Sus. declaration		Voluntary guides for industry	Sustainability siting code under development	
- Building related	Rainwater tanks not required		Voluntary guides	Green star type ratings for CO_2	
- Precinct related	Still under development →	?	Voluntary guides	Potential use for sustainability	
Climate change policies	CSG issues	? ←	Under review	Green star rating	Voluntary action
State government oil vulnerability strategy (OVS)	Not released – Lack of strategic information is a significant issue and a barrier to landuse change		Draft Council OVS in review and could be incorporated in new planning scheme	Clean energy community plans, if pursued by new state government	Current policy development is unlikely to produce OVS plans – rely on local action
City of Gold Coast planning scheme	Scheme under review in 2015		Strategic framework advocates a city 'shaped by clever design' & transit supportive urban communities (TOC)s		
- Planning strategies - Planning scheme codes standardised	Detached house self-assessable in all zones is a density barrier		Transformation of existing suburbs to TOCs	Gold Coast planning scheme aspirational goals	G.C. current scheme energy efficiency policy, but could be lost

4.3 Queensland planning system reforms

The Liberal-National Party (LNP) Queensland Government, elected in March 2012, introduced significant reforms to shift the planning system away from the objectives of the *Sustainable Planning Act 2009,* under which the Gold Coast and most other cities were in the process of reviewing planning schemes prepared under the previous *Integrated Planning Act 1997.* The reforms were driven largely by the perceived needs of the development industry, arising from a series of planning forums in 2013 conducted by Department of State Development, Infrastructure and Planning (DSDIP). A new planning system was intended to advance objectives that reduce planning red tape and empower local governments, to focus on ensuring the state's continued growth and prosperity, including the following key components (DSDIP 2013a):

a. New planning legislation … will streamline assessment and approval processes; drives prosperity through a four-pillar economy, including development and construction; and empower local governments to better plan for their communities. The pillars are agriculture, tourism, mineral resources and construction activities.[23]
b. A single statutory State Planning Policy (SPP) that replaces 10 current policies with a new framework comprising 18 interest areas under five themes, mandatory requirements and non-statutory guidance material. The SPP identifies the state's interests in planning and development and how these are to be dealt with in planning instruments, council development assessment processes and in designating land for community infrastructure. (DSDIP 2013a)
c. New style statutory regional plans give strategic direction, shaped by the planning reform agenda, which focus on regional economic development, and align with the state's interest in planning and development; thus requiring a new regional plan for South East Queensland.

All the proposed planning instruments were aimed to meet the perceived needs and expectations of the Queensland community, as shaped by the LNP state government objectives to attract economic and infrastructure investment and 'support the ability of industry to respond quickly to new opportunities and markets or establish essential supply chains' (DSDIP 2013a). In simple terms it would be growth and prosperity oriented as indicated in the strategic intent of the new single SPP.

4.3.1 New State Planning Policy

The new SPP was released on 2 December 2013 and will be subordinate to the *Sustainable Planning Act 2009* until it is superseded by the new planning legislation to remove any nexus with the ecological sustainability focus of the current Act[24]. The new SPP expresses the state's interests in land use planning and development around five key themes shown diagrammatically in **Figure 4.10.**

[23] This four-pronged program has since been overtaken by the ALP state government change of direction.
[24] The SPP was amended in 2014 after submission of this thesis and will be refined by the ALP government.

Figure 4.10: Queensland single State Planning Policy state interest themes

Source: Department of State Development, Infrastructure and Planning (2013b: 15)

The SPP 'is a broad and comprehensive statutory planning instrument. It sits above regional plans, standard planning scheme provisions and planning schemes within the hierarchy of planning instruments outlined in the planning Act' (DSDIP 2013b: 9). The SPP links the resources industry to the fossil fuel economy that 'supports the needs of other industries and communities across Queensland, Australia and the world through the supply of valuable commodities including coal, coal seam gas, minerals and petroleum.' (DSDIP 2013b: 23)

Under the key theme of economic growth, the SPP asserts that 'planning supports employment needs and economic growth by facilitating a range of residential, commercial, retail and industrial development opportunities, and by supporting a strong development and construction sector' (DSDIP 2013b: 22). The SPP links this with the liveable communities and housing theme to advocate liveable communities that are well-serviced, accessible and attractive environments, and housing supply and diversity. Importantly, 'planning and development decision-making … influences the quality of urban design, which helps shape the liveability of our places and contributes to community wellbeing by guiding the placement and sequencing of facilities, services and housing within a sustainable environment' (DSDIP 2013b: 16). More generally, The SPP principles require positive responses to change, challenges and opportunities to ensure 'the outcomes and processes of the planning system must … enable decision-making that is based on the best available knowledge to objectively address the needs of today and the future' (DSDIP 2013b: 13). The state interests for both themes are to be met through planning schemes by a combination of measures, summarised as:

a. facilitating the consolidation of urban development in and around existing settlements and maximising the use of established infrastructure and services for development and urban renewal of land in appropriate locations
b. identifying suitable land for residential, commercial, retail and industrial development, and providing a mix of zone types and locations that consider existing and anticipated demand, the nature of surrounding land uses, opportunities for mixed uses
c. facilitating the development of mixed-use precincts to provide opportunities for a wider variety of uses, local employment, small businesses and innovation
c. ensuring an adequate supply of land suitable for housing to meet the diverse and changing needs of different communities, now and into the future, in areas that are accessible and well connected to services, employment and infrastructure
e. facilitating a diverse and comprehensive range of housing options that caters for the current and projected demographic, economic and social profile of the local government area
f. providing for best-practice, innovative and adaptable housing and urban design that promote attractive, adaptable and accessible built environments and enhance personal safety and security
g. facilitating the provision of pedestrian, cycling and public transport infrastructure with connectivity across all networks [TOD is not mentioned]. (DSDIP 2013b: 16-22)

The state interests for infrastructure include transport, energy and water supply. The SPP advises that 'providing safe, reliable and affordable energy and water supply is vital to meeting the basic needs of communities and for Queensland's economic prosperity' (DSDIP 2013b: 36). Yet curiously it is silent on any form of renewable energy, or any role of planning schemes to facilitate it. On the other hand, transport is very much a local planning matter as it 'provides access to employment, social services and recreational opportunities, and drives economic growth by supporting productive and successful industries and businesses' (DSDIP 2013b: 38). Consequently, state interests are to be met through planning schemes by 'facilitating land use patterns and development which achieve a high level of integration with transport infrastructure and support public passenger transport and active transport as attractive alternatives to private transport' (DSDIP 2013b: 38). Lots above 0.5 ha near transit require special assessment.

Implications for thesis research

The implications for this thesis research of the strategic objectives of the LNP's 2013 planning reforms differ from the previous planning system framework in three ways:

a. Explicit emphasis is placed on prioritising mining and fossil fuels extraction in support of the four pillar economy to drive Queensland prosperity.
b. The State Planning Policy is silent on renewable energy and climate change.
c. Explicit emphasis by frequent repetition is placed on construction led growth, based on increasing land supply for residential and other development.

Prioritising resource and fossil fuels (coal and coal seam gas) extraction as one of the four pillars of the new economy ensures statewide energy security in the short–medium term, without any explicit reliance on renewable sources. The future oil depletion scenario at the heart of this thesis could be strongly mitigated in relation to stationary energy and potentially in transport fuels. However, all these resources contribute significantly to greenhouse emissions, both in extraction and in consumption (i.e. by burning). Hence the state is continuing to promote the fossil fuel industry as an overriding priority, to the detriment of climate change mitigation efforts. The conundrum of balancing economic development, energy security and climate change highlights the global wicked nature of continuing petroleum and other fossil fuels use.

The strategic importance of construction led growth as one of the four pillars of the new economy appears to emphasise an adequate supply of residential land. The SPP signals a retreat from the existing commitment to a compact growth model, although 'consolidation of urban development in and around existing settlements' is mentioned (DSDIP 2013b: 17). More emphasis is on improving the types and diversity of housing by greenfield, infill and redevelopment. Planning is to include 'principles of best-practice urban design' within 'a sustainable environment' and encourage 'land use patterns that support sustainable transport' (TOD is not mentioned) (DSDIP 2013b: 16-17, 38). The SPP is supported by non-statutory guidance material including the Next Generation Planning Handbook that is discussed in section 2.2.3, but there is no statutory requirement for compact urban form. The wider implications of what a 'sustainable environment' actually means needs to be clarified, but the SPP suggests an approach that resembles the modernist world view focussing on economic values, as discussed in section 2.3.2. The SPP objectives do not align with those expressed in this thesis to adapt residential development to the oil-constrained future. The conclusion is that this hiatus in the Queensland policy setting agenda is an opportunity to raise the oil depletion problem. Further commentary about the ongoing state-led planning reform is in **Appendix H**.

4.3.2 New SEQ Regional Plan

The LNP government planning reforms included a new generation of regional plans that 'will focus on those state issues that require regionally-specific policy direction to supplement the policy direction and associated guidance about state interests in the

SPP', as outlined in DSDIP Fact Sheet 5 (DSDIP 2013c: 1). The fact sheet stresses that Regional plans will focus on addressing state issues through a land use planning response. Not all issues that occur within the region will require a regionally specific policy response, but only for an issue that:

a. due to its nature cannot be addressed by a single local government
b. involves the resolution of conflict between two or more state interests
c. is identified by the regional planning minister as requiring a regionally-specific policy response. (DSDIP 2013c: 2)

The five DSDIP Fact Sheets for the proposed SEQ Regional Plan provide a policy framework partly shown in **Figure 4.11**. The plan will give 'strategic directions about the nature and location of future growth, to guide the preparation of [local planning instruments]' (DSDIP 2013c). The SEQ Regional Plan would consider the SPP principles and objectives, but only resolve any competing state interests for the region where such a regional reflection is considered necessary by the planning Minister.

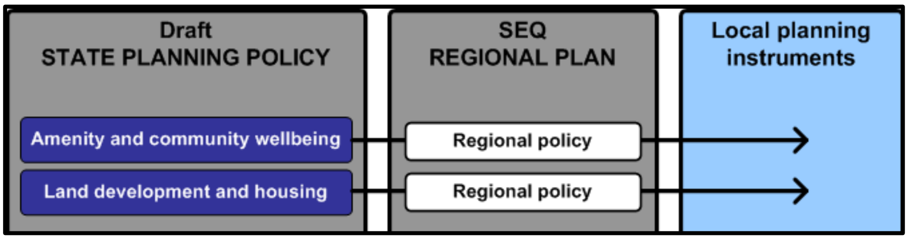


Figure 4.11: Regional Plan partial schematic land use policy framework

Source: After DSDIP (2013c: 2)

The DSDIP Fact Sheet 4 *regional snapshot* for the new SEQ Regional Plan indicates that in 2011, '3.1 million residents lived in just over 1.2 million homes, of which approximately 23.2 per cent were a multiple dwelling such as a townhouse, unit or apartment' (DSDIP 2013d: 1). The average occupancy rate has increased slightly to 2.5 across the region. There is an estimated 15 years supply of land across the whole region that is suitable for housing and urban growth will require about 803,000 new dwellings by 2031. Over the period 2006–2011, approvals for multiple dwellings were about 37 per cent of all dwelling approvals, of which Brisbane and Gold Coast areas accounted for 70 per cent of infill proposals. The median size of new residential lots has gradually decreased over the decade to 524 m^2. (DSDIP 2013d: 1).

Private vehicle use continues to dominate the way people travel in the region with over 80 per cent of all trips. However, the total number of private vehicle movements on the network each year is slowly decreasing, because residents are less likely to make multiple journeys each day. Public transport usage rates 'have increased at almost double the rate of population growth over a comparable period—a 19 per cent increase in usage compared to 11 per cent population growth during 2004–2009' (DSDIP 2013d: 2). Public transport trips to Brisbane's CBD for work purposes have increased to three quarters of all such journeys, while its use in other sub-regions has remained relatively stable. Journeys to work are relatively self-contained within the Gold Coast, with 87 per cent of trips originating and terminating there. (DSDIP 2013d: 2-3). The implications of the SEQ regional plan reform for this research are set out below.

Implications for thesis research

One implication for this research is that the LNP 2013 proposed SEQ Regional Plan is likely to give only broad strategic direction about the nature and location of future growth, rather than planning guidance for desired outcomes across a wide range of themes of integrated planning. Detailed strategic planning is more clearly the function of local government. In the semi-self-contained City of Gold Coast, this facilitates an innovative approach, as indicated in the Land Use Plan for the Southport area.

The regional snapshot shows that less than 40 per cent of the target 60 per cent of infill dwellings is being achieved, and that the average lot sizes reflect a continuing suburban pattern of urban growth. The growth in dwellings of 240,000 over the period 2001-2011 is considered to be abnormal, because of the housing bubble early in the decade and the dramatic slowdown since 2009 in the great recession. The regional requirement for 800,000 new dwellings by 2031 points toward the SPP objective to increase the housing land, even an estimated 15 years supply of land across the region suitable for urban growth. It nevertheless gives scope, if not an imperative, to increase the density of the urban form within the existing urban footprint, and to support an efficient public transport system, particularly in the reference Gold Coast area. In contrast, public transport focussed on the Brisbane CBD and adjacent fringe area demonstrates a large mono-centric employment node can sustain a viable system. The slow decrease in private vehicle use for journeys to work is likely to grow significantly in an oil-constrained future, reinforcing the need for closer integration of public–active transport in an efficient urban form. This suggests limiting urban land expansion (sprawl).

Development of the future sustainable urban environment, required by the SPP (DSDIP 2013b: 16) and implied in the regional plan, may be contingent on the adaptive strategies for oil depletion, including the construction of the built environment and the evolving urban form. Such guidance is unlikely in current SEQ Regional Plan outcomes. However, the evidence base for including such guidance could be provided by the state publishing an oil depletion strategy that was in a preliminary form in 2008 (Queensland 2008). Development is intended to be resilient to the projected effects of both climate change and oil supply vulnerability. These policies act as moderating factors in residential development. They present no barrier to alternative forms of development, although there is no statutory commitment to compact urban forms. However, many of the desired regional outcomes are aspirational and, therefore, highly dependent on the quality of the local planning strategies and measures, expressed in local government planning schemes. The Gold Coast planning scheme is a relevant case that in addition to the commentary in section 4.2.5, warrants a special mention in the next section due to a declaration made just as this thesis was being completed.

4.3.3 Southport Priority Development Area

As noted in section 4.2.3, the draft *Bold Future Planning Scheme* was submitted by the Gold Coast City Council (GCCC) in February 2012 for the first state interest check. The change of council elected representatives in April 2012 caused the draft plan to be withdrawn. The new Gold Coast City mayor announced a new style *City Plan* as being a people's plan to make the city 'the most liveable, affordable and prosperous place in Australia' and an opportunity for innovation (Tate, T, media release, 5 September 2012). The plan had not been redrafted as at late 2013 because of the ongoing planning reforms, including amendments to the planning legislation and adoption of version 3 of the QPPs. Meanwhile planning in preparation for the 2018 Gold Coast Commonwealth Games was proceeding, but held up by these delays. On 4 October 2013 the state government declared Southport as a Priority Development Area (PDA) under the *Economic Development Act 2012*, at the request of City of Gold Coast.

This means the Southport area shown in **Figure 4.12** is excised from the city for planning purposes and a separate planning process is underway to develop Southport as the key central business district for the city, including Games venues and nearby Games village. Normally the planning for a PDA would be undertaken by Economic Development Queensland, but in this case the task has been delegated back to the GCCC. Effectively this means that the 2009 draft Central Southport Master Plan (GCCC 2009) can be completed ahead of the overall planning scheme as a draft development scheme. The draft was expected to be released in March 2014, with the final scheme expected to be in place by mid-July. Until the scheme is finalised, development within the PDA is regulated by an Interim Land Use Plan (ILUP) which was released with the declaration (DSDIP 2013e). The PDA area and precincts are shown in **Figure 4.13**.

Figure 4.12: Southern half of Southport priority development area

Source: Gold Coast City Council (2009) with permission

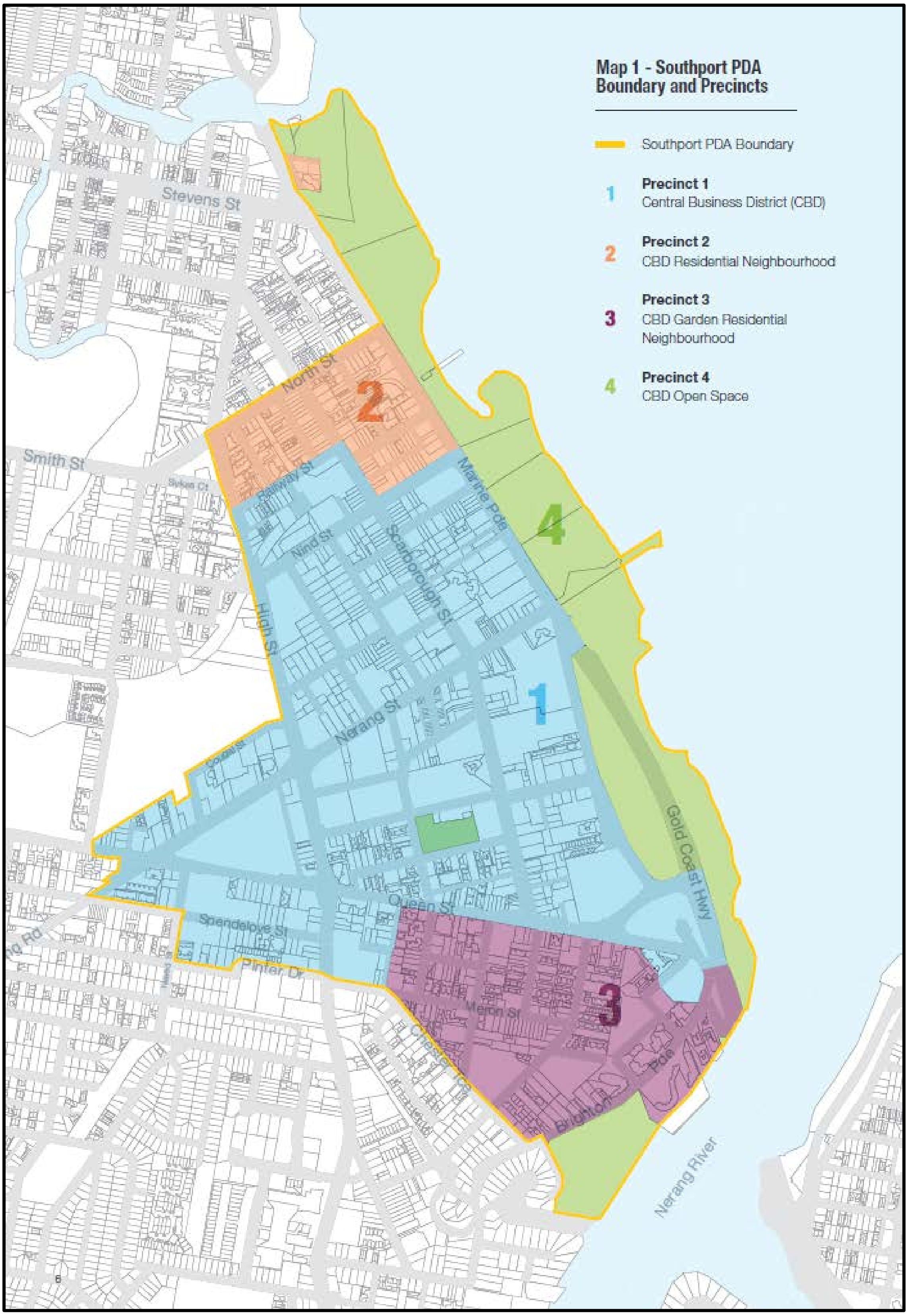


Figure 4.13: Southport priority development area precincts

Source: Department of State Development, Infrastructure and Planning (2013e)

4.4 Conclusions on development and planning factors analysis

The chapter has addressed research objective 2.1 by describing and analysing the conceptual framework intervening factors of oil-related inputs into *residential development* and the moderating factors related to *planning and regulation* of urban development at the City of Gold Coast for relevance to the modified initial thesis propositions.

The intervening development factors include the use of alternative materials and sources of energy. Alternative sustainable building materials and construction principles—including eco-efficiency more durable materials, products and components to extend the life cycle of buildings—will have adaptive effects to increase the resilience of settlements to oil constraints. In the Queensland and SEQ context, the main energy substitutes involving the exploitation of coal seam gas—which will be increasingly important in mains electricity generation and in the local manufacture of petrochemical plastics and paints—will have a short to medium term mitigating effect.

The analysis of the moderating factors introduces a broad range of state legislation, strategic planning related policies (SPP) and building related codes, which since 2012 have all been subject to a significant reform process. The state and regional level controls affect the planning and design of urban residential development in the context of the representative building typology devised for this thesis research. The draft 2012 Gold Coast strategic framework espouses the Next Generation Planning principles discussed in section 2.2.3. However, the detailed objectives may change in the final City Plan. The strategic residential concepts are considered to be aspirational goals. They need much deliberate detailed planning in both existing suburbs and newly developing communities, to adapt to an oil-constrained future.

Various codes and rating systems apply in the City of Gold Coast to sustainable development assessment in the context of climate change mitigation. The voluntary sustainability rating principles have desirable effects of reducing oil and gas demand, with concomitant economic and environmental benefits. The importance of the property and building industry drivers as important barriers to change must not be overlooked. The inter-related planning system also becomes a barrier unless sufficient strategic information is released to guide both public and private decision making about future oil constraints. Only a few local governments in South East Queensland have taken the initiative to make such information available and in limited application to council oriented activities that may affect the community. Table 4.2 summarises the main effects of the multiple moderating factors on the planning and design regulations of residential development in the City of Gold Coast.

The change to a LNP government in March 2012 initiated a major overhaul of the planning framework and climate change policies. Because of the reversion to ALP in 2015, there is still no draft planning legislation, clear state policy for climate change adaptation, or future oil constraints, which would guide local government and the public. Nevertheless the achievement of this reform is relevant to the outcomes of this research and in the wider public policy arena. It is concluded that while the current strategic planning tools have a potential beneficial, but not mandatory, influence on the forms of urban development, the future is uncertain and not clarified by the SPP.

The overall conclusions are that the intervening development factors and the moderating planning and regulation factors could influence planning and design of residential development in ways that, with careful oil-related policy refinement:

a. reduce or avoid oil and gas inputs, so as to decrease reliance on the oil economy: the mitigation effects to conserve oil supply and cope with price vulnerability
b. adopt planning outcomes for the urban form that anticipate changes in oil supply and cope with the consequences: the adaptation strategies to increase resilience
c. encourage an oil-depletion sensitive response from the building industry and real estate investment market.

The empirical facts, analysis and findings of the Part 2 research are intended to provide inferences and constructs, with which to develop insights, theoretical concepts and models as grounded theory in Part 3. This chapter provides the following constructs:

a. In terms of the mitigation and adaptation terminology proposed in section 3.2.2, the intervening factors have mitigating effects on the energy supply available at the Gold Coast. Alternative sustainable building materials—including eco-efficiency, more durable materials, products and components to extend the life cycle of buildings—will have adaptive effects to increase resilience to oil depletion.

b. The state and regional level controls affect the planning of urban residential development including population growth management; strategic frameworks of the planning schemes; and compliance with the SPP for liveable communities and housing, development and construction, state transport infrastructure and energy.

c. The draft Gold Coast strategic framework espouses the Next Generation Planning Handbook principles. However, the strategic residential concepts are considered in this thesis to be aspirational goals. They need much detailed planning in both existing suburbs and newly developing communities, to adapt residential development to an oil-constrained future.

d. The local planning instrument (planning scheme) affects the planning and design of urban residential development in the context of the representative building typology devised for this thesis research. The local planning outcomes sought for the residential zones require that any proposed development:

    1. encourages and facilitates urban consolidation and the efficient use of physical and social infrastructure

    2. provides for an efficient land-use pattern that is well connected to other parts of the local government area

3. is designed to maximise energy efficiency, water conservation and public/active transport use.

e. Despite these strategic and policy directions, the private land and building industry is slow to change from the predominant detached housing model in most greenfield development areas, making a transition to a more compact urban form problematic. These property and building industry drivers are important and conservative barriers to change.

f. The new SPP objectives do not align with those expressed in this thesis to adapt residential development to an oil-constrained future. The strategic objectives also differ from the planning system framework prior to 2012 in three ways:

   1. Explicit emphasis is placed on prioritising mining and fossil fuels extraction in support of the four pillar economy to drive Queensland prosperity.

   2. The State Planning Policy is silent on renewable energy and climate change.

   3. Explicit emphasis by frequent repetition is placed on construction led growth, based on increasing land supply for residential and other development.

The intervening factors in oil-related inputs and the current moderating planning factors in land development and building are applied to the case studies in Chapter 5.

Chapter 5

Pilot case studies

Earth provides enough to satisfy every man's need, but not every man's greed. Mahatma Gandhi

This chapter builds on the Part 2 empirical research reported in sections 3.3 and 4.1 on material flow analysis of petroleum-related inputs into urban residential development; to apply the case study strategy in section 2 of Appendix A; and report on the pilot studies set out in Appendices D – G. The individual case findings lead to a cross-case analysis to draw conclusions about relative oil vulnerability. The outcomes of this analysis form the basis for comparing and contrasting the sample range of the residential dwelling typology that was described in Chapter 2. The discussion draws study-wide inferences applicable to the residential typology. The chapter concludes with a discussion about the limitations of the pilot case study approach and offers suggestions for further research to extend the cases to the full residential typology.

The term 'dwelling unit' applies generally to residential accommodation, ranging from detached houses to high rise tower apartments. The word 'unit' is an abbreviated form of expression, especially for apartments or flats (see also the glossary).

5.1 Study cases and strategy

The purpose of the case study design in Appendix A is to apply part of the initial conceptual framework model summarised in **Figure 5.1** to the urban transect of the City of Gold Coast. The cases highlight differences in design and construction of the representative residential typology as illustrated in **Figure 5.2** from section 2.2.4.

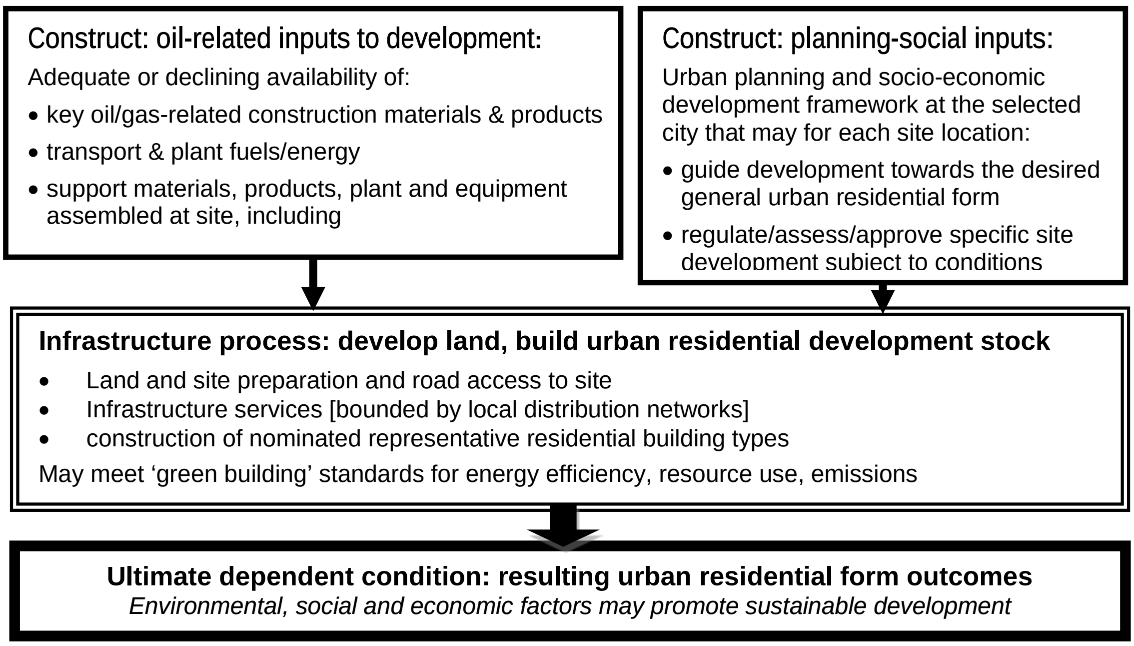


Figure 5.1: Urban development conceptual framework

Source: The author

Figure 5.2: Representative residential building typology

Photos by the author

5.1.1 Study cases

The cases shown in Figure 5.2 and analysed in Appendices D – G broadly reflect the Gold Coast City urban transect planning categories:

Case A: Detached single storey house: the predominant suburban neighbourhood.

Case B: Low rise apartment building of three storeys (and a partial fourth excised level) over parking at ground level with lifts: the urban neighbourhood.

Case C: Medium rise, apartment building of six storeys with one parking basement and lifts in an elongated rectangular shape: inner urban neighbourhood.

Case D: High rise apartment tower of modified 30 storeys with three parking basement levels and lifts: the central business district and activity centres.

The gaps in the typology include:

- Rural residential detached houses on large lots
- two storey detached houses
- two storey attached town (row or terraced) houses
- three storey walk-up apartments (which effectively can no longer be built)
- apartments over shops and offices in mixed use developments.

Common elements of the residential buildings include:

- the land development and road construction
- the manufacturing and installation of internal building components.

The likely impacts of oil depletion in relation to the common elements will affect the vulnerability of future development in a non-differentiated way. These factors therefore may be studied in just one case and extrapolated to the other cases; or considered separately. Nevertheless the ubiquitous impacts should be taken into account in the overall assessment in Chapter 7 of adapting urban residential development to an oil constrained future and the possible impact on urban form.

5.1.2 Case selection issues

The process of selecting suitable projects for the cases nominated above became protracted by changing circumstances during the research program. One potential site chosen early in the program that fulfilled three of the cases failed to eventuate. The search restarted for two or three separate sites meeting the criteria in Appendix A section 2.3.3. A suitable site for both the case B low rise apartments and the case C medium rise apartments was discovered in a central location. However, it became unavailable due to the development company going into administration at a critical stage of arranging for the data provision.

Alternative sites for a three storey apartment building case were searched for, but it was complicated quite coincidentally by innovative architectural design. One example set larger two storey units above single storey ground floor units. A second example positioned two buildings with two units per floor above a large common basement. Neither of these types was suitable for comparative analysis. Another variation was an older style of two or three levels of units over ground level parking. A further complication was the lack of recently approved and built traditional three storey walk-up apartments as developers anticipated the changes to building regulations to meet universal design principles under the *Disability Discrimination Act* (Australia) and the Building Code of Australia, and so they installed lifts (see Chapter 4 section 4.2.4).

Eventually a site was selected with potential for cases B and C. It is similar to other medium density projects situated in the Broadwater coastal district north of Southport. A second site in Surfers Paradise was selected for the case D high rise tower. However, like other prominent sites, a detailed description of these locations and their context is problematic, because of the need to maintain anonymity of the development under the ethics approval. Full details are held at Bond University.

5.1.3 Case study strategy

The case study strategy in Appendix A section 2.3.3 summarises the approach to what are complex material flow analyses with significant data gaps and inferential uncertainties. There are also design-related extraneous variables both across cases and even within cases, which are discussed in the cross case analysis in section 5.6. The inductive reasoning in this low-constraint exploratory research draws relationship conclusions in the cross-case analysis, which informs the development of grounded theory in Chapters 6 and 7. The strategy to address complexity and achieve valid results is to:

- focus on the relevant issues that may affect oil and gas inputs into development
- make simplifying assumptions where considered reasonable to do so
- make appropriate empirical observations and record the results, so that they can be replicated by other researchers. The energy intensity indices are at Appendix C
- rationally interpret the empirical observations with inductive reasoning
- be aware of the potential differences in energy demand indicated in Table A.1

- avoid logical errors in deriving constructs and in inductive reasoning, such as the all-or-none bias and the similarity-uniqueness paradox
- be aware of the possible null hypothesis – that there is no significant difference between two or more materials, components, or even residential building types in respect of oil and gas inputs
- avoid possible ex-post-facto (after–the-fact) fallacies by taking care to draw only tentative conclusions from the data.

The empirical data for each case is recorded in the accompanying CDROM and detailed in Appendices D - G as a stand-alone report. An archival research approach is used to collate data sets provided by participating developers and analysed to create vulnerability indices for each case, based on embodied energy intensity per unit of gross floor area. The cases are tested in differing appropriate ways to determine the degree of significance to a reasonable confidence level and validity. The cases are also compared on the basis of the energy intensity per bedroom and occupancy rate for the typical dwelling units. The essential specific questions to be asked about the conclusions of each case are:

a. Is the case is considered to be representative of the residential typology?
b. Do the limitations of the analysis of oil inputs threaten the validity of the research in relation to quantitative or qualitative data?
c. Should the analysis be deemed to be complete for the purpose of the thesis?
d. Are the results sufficient to draw comparisons with other cases?

5.1.4 Case study summaries

The main findings for the individual cases described in section 5.1.1 are summarised to provide sufficient information to follow the cross-case comparison in section 5.6:

1. Sections 5.2 – 5.5 describe for each case the development context; building details with relevant photos and floor plans; the construction process; summary results for oil-related inputs; and other important information relating to building modification for analysis purposes.
2. Each case records the data findings. The key land development, building construction and transport related components are categorised as:
    - direct oil input or gas – e.g. bitumen products, transport fuels
    - indirect input: oil or gas as a feedstock - e.g. petro-chemical products
    - embodied energy on a per unit of quantity (energy intensity) basis
    - key aspects transport of materials to site and workforce considerations.
3. This section discusses the oil and gas inputs, sensitivity testing, and the main limitations in identifying and detailing them in the pilot case study.
4. The final section highlights the oil vulnerability conclusions of each case; answers the case questions noted above; and makes suggestions for further research.

5.2 Pilot case study A – single level detached house

This pilot case study reported in Appendix D investigates a completed project on greenfield land in the Coomera district (**Figure 5.3**). The detached house was constructed on the basis of a typical land-house package where the developer had total control of all operations. This is regarded as the 'base case' benchmark, with which all other cases are compared.

Figure 5.3: Case Study A Context Photo

Source: Developer, used with permission

5.2.1 House information relevant to the case

This section summarises the detailed information for this case set out in section 2 of Appendix D. The case developer provided the building file including plans and detailed drawings, a bill of quantities (BoQ) with specifications and schedules, and construction information. Bond University holds these thesis records. The developer is a national residential construction company with a long history of land-house packaging of architect designed project homes that are demonstrated in so-called 'display villages' in newly forming suburbs. House designs in the product catalogue are finely tuned to meet the target market to suit first home buyers in the most cost efficient manner, with scope to individualise similar designs by roof and facade variations.

Building description

The case house construction is face brick veneer on timber wall frames and roof trusses, lined with plasterboard internal walls and ceilings. The foundation and ground floor comprise a waffle pod concrete slab with 300 mm foam block cores, which minimises trenching and ground disturbance. The case study example has a concrete tiled hip roof as shown in **Figure 5.4**.

Figure 5.4: Case study A house front view

Source: Photo by the author

The floor plan at **Figure 5.5** shows the house comprises 3 bedrooms, 2 bathrooms, study, open plan combined family-dining area, double lock-up garage, outdoor covered area. The case is equivalent to four bedrooms for analysis purposes. Typical occupancy: 4 persons (2 adults and 2 children as a nuclear family):

House gross floor area:	132 m^2	Site area:	570 m^2
Double garage area:	37 m^2	Site coverage:	32 %
Porch and covered patio:	16 m^2	Carpeted area: approx.	41 m^2
Total GFA:	**185 m^2**		

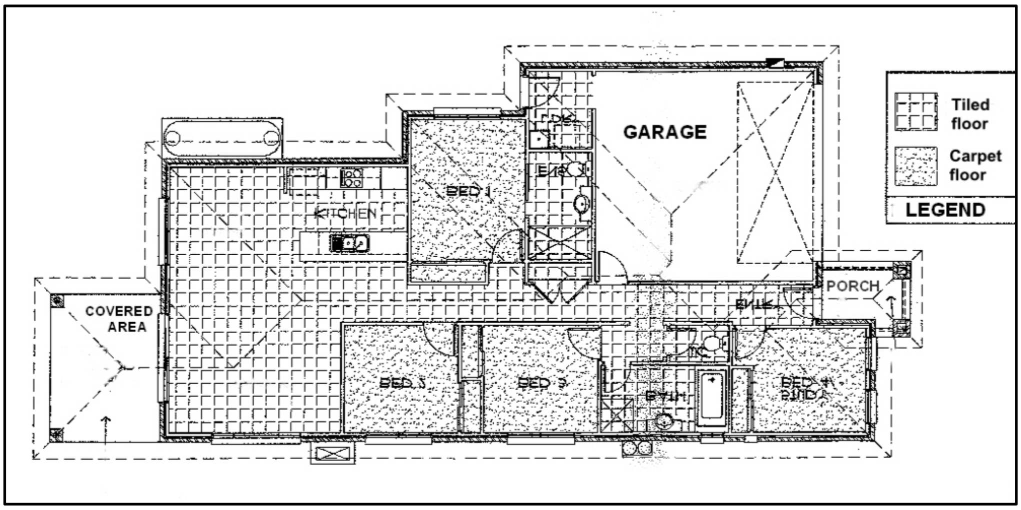


Figure 5.5: General layout of case study A house

Source: Provided by case study developer with permission

Construction process

While this overview of the construction process is specific to the house case study, it is generally applicable to single-level slab-on-ground dwellings, with a few variations:

1. The domestic scale house building process takes about 8-12 weeks to practical completion. The process is energy intensive for transport of materials and the workforce in a single house project, especially in a greenfield environment.
2. The process for simultaneous building projects enables economies of scale in delivery of materials and transport of the workforce, but is not often feasible.
3. Construction practices are widely standardised within and between states because of Building Code of Australia regulations and application of Australian Standards.
4. An increasing proportion of house foundations utilise waffle pod slabs to improve efficiency, minimise ground disturbance, reduce labour effort and therefore costs. They are not suitable for sloping sites, where traditional concrete slab floors are also unsuitable. Once laid, the slab is trafficable the next day as a work platform.
5. Building components are partially factory prefabricated—i.e. wall frames and roof trusses—and delivered by flatbed crane truck to the site. Wall frames are erected manually. Roof trusses are erected with crane assistance and non-truss components added manually, with no or minimal scaffolding in use. Stormwater guttering, windows, plumbing fixtures (e.g. bath) and electrical rough-in are then added.

6. The stage to lock-up comprising roof tiling, external doors, windows and wall insulation, and external brick cladding makes the building weatherproof and secure.
7. Once the building is weather and vandal proof, the interior structural work is completed with wall linings, doors and skirtings; air-conditioning, mechanical, electrical and plumbing services; and ceilings lined with plasterboard.
8. The kitchen, bathroom and bedroom cabinetry and joinery fitout uses factory pre-fabricated items where feasible. Once fitted out, the floors and walls are finished.
9. The last stage is finishing of the internal areas with painting, window treatments, carpets; installation of electrical appliances, fittings and lighting; plumbing and drainage internal and external fit off; fencing, driveway and landscaping.

5.2.2 Oil and gas inputs

This section records the inputs for the case and makes brief comments on the findings.

Results summary

An inventory of main building materials and components relevant to this study is shown as a tabulated presentation in Attachment D.1 of Appendix D. A summary of the tabulated input results is presented in **Table 5.1** below:

Table 5.1: Summary of case A detached house analysis

Oil related direct input:			
Bitumen minimum	1.6	m^3	
Oil/gas related indirect input (some partially or not quantified):			
Petrochemicals –			
PVC pipes (various diameters)	113	m	
Polyethylene sheet	150	m^2	
Expanded polystyrene waffle pods	51	m^3	
PVC cable sheathing			(Not available)
Sealants and paint (total area)	554	m^2	
Melamine kitchen cabinets and robe shelving			(Items only)
Carpet	41	m^2	

Recorded estimated embodied energy:	***Per dwelling***	***Per m2 GFA***
Total land/road development (GJ)	117.70	0.64
Total essential infrastructure (GJ)	49.90	0.27
Total building materials (GJ)	1930.05	10.43
Household appliances and equipment (GJ)	166.25	0.90
Total freight transport (20 km distance) (GJ)	9.52	0.05
Total process embodied energy approx.	**2273.42**	**12.29**
Direct and indirect oil and gas inputs = 42 GJ plus waffle pods 359 GJ		

A similar Melbourne case study enabled the additional direct energy requirements (DER) amounting to 545 GJ to be added for this case study (Crawford 2011: 90). The total estimated embodied energy for the recorded material items (2273 GJ) and DER (545 GJ) of the 185 m2 house is **2818 GJ**. This compares with an estimated 3994 GJ for the 307.7 m2 Crawford case study house (2011:78, 94), which has a 46.5% larger gross floor area. If the subject case were scaled up, it would be the order of 4128 GJ. The 3.4% difference may be partly accounted for in the more open room layout and fewer walls in the Crawford case. Nevertheless, this result is considered to be quite reasonable for the purpose of this PhD thesis and the discrepancy is within tolerance limits, given the approximations of some significant construction material items.

5.2.3 Analysis of oil inputs findings

This section discusses the oil and gas inputs and notes other key inputs and issues in the case. It became apparent from both this case study and the Crawford study (2011: 78-95) that the assessment of inputs is a complex exercise, even for a detached house. It is difficult to assign quantities and energy to all materials and elements. The subtleties of oil and gas inputs are easy to lose in the inventory, especially in relation to upstream materials processing. The overall analysis should therefore be regarded as a conservative estimate of the material and energy inputs into this building type, regarded as the base case. The total direct and indirect oil and gas inputs amount to 401 GJ, representing 21 per cent of the structural energy of 1930 GJ.

The greatest impacts associated with buildings are often related to consumption of energy (Junnila and Horvath 2003, quoted in Crawford 2011:42). The direct energy consumption for construction of the detached house of the type in case study A is of the order of 350 kWh of electricity at peak rates when taken from mains power, according to the case construction manager. This is a small amount and only about half of a typical three months of operating power. In any case it is supplied from coal fired power stations. It reinforces the view expressed above that the operational energy is the main factor.

As in all the other cases of the study, transport of materials and labour is the largest direct oil-related input, based on current transport fuels. Hence the deceptively small recorded transport embodied energy (9.52 GJ) is not the whole story in examining the possible oil related impacts in a future oil constrained scenario. The site is embedded in a housing estate that is some 4.5 km from a major arterial road—the Pacific Motorway—and is approximately 8 km from a district concrete batching plant. This is relatively convenient because the Coomera district is an active housing development area. Further transport comments are made in section 5.6.4.

Although there are significant gaps in the material data and additional research is recommended, the overall case conclusion is that the material flow assessment of the single storey house for oil and gas inputs provides an adequate basis to make preliminary inferences from differential analysis of the cases.

5.3 Pilot case study B – low rise apartment building

This pilot case study reported in Appendix E investigates a completed low rise three storey (over parking) apartment building in a medium density development in the waterfront area of the City of Gold Coast, as explained in section 5.3.1. While the case is not in an inner city location, it adequately meets the criteria in section 2.3 of Appendix A. The project is improved for the purpose of the analysis, as indicated in **Figure 5.6**, by excising a partial fourth level that contains the main bedroom and bathroom of the penthouse. It then fits into the residential typology category B–3 storey low rise, medium density apartments with lifts–that represents the inner urban transect. The building is an economical rectangular shaped structure, and is considered to be representative of recent medium density residential developments in the city.

5.3.1 Building information relevant to the case

As noted in section 5.1.2, a detailed description of the case location is problematic, because of the need to maintain anonymity of the development. The case developer is an international construction company with an Australian associate company that uses local consultants for design and construction. This site is similar to other medium density projects situated in the Broadwater coastal district north of Southport. The development has been subject to the *Integrated Planning Act 1997* (Queensland), and the 2003 Gold Coast City Planning Scheme. The building is part of a large master planned complex on redeveloped land that was approved with a site-specific development code, offering a range of 2–4 bedroom apartments.

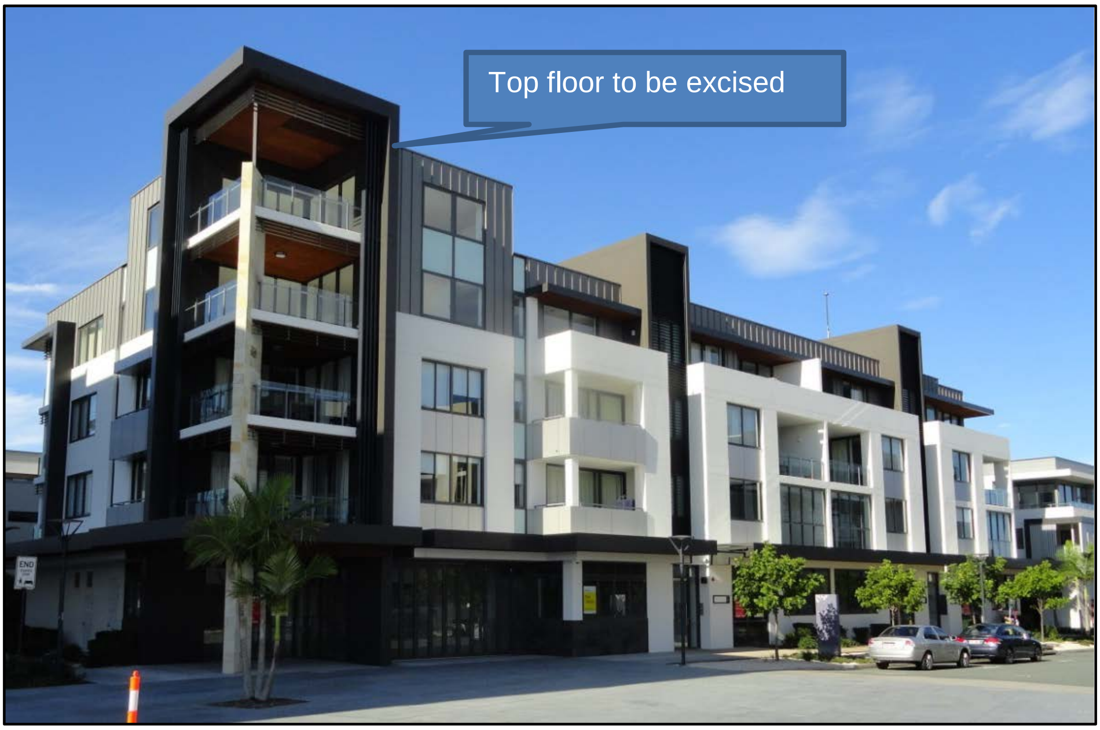


Figure 5.6: Case study B apartment building viewed from road

Source: Photo by the author

Building description

The form of construction is a steel reinforced concrete structure with a ground level secure parking area and offices, three levels of apartments (plus an extra partial fourth storey for the penthouse master bedroom) and a sheet steel roof. The 15 apartments are arranged in two sections, each with a separate street access and a small entry foyer as indicated in **Figure 5.7**. Each section has a lift and fire stair access to all floors.

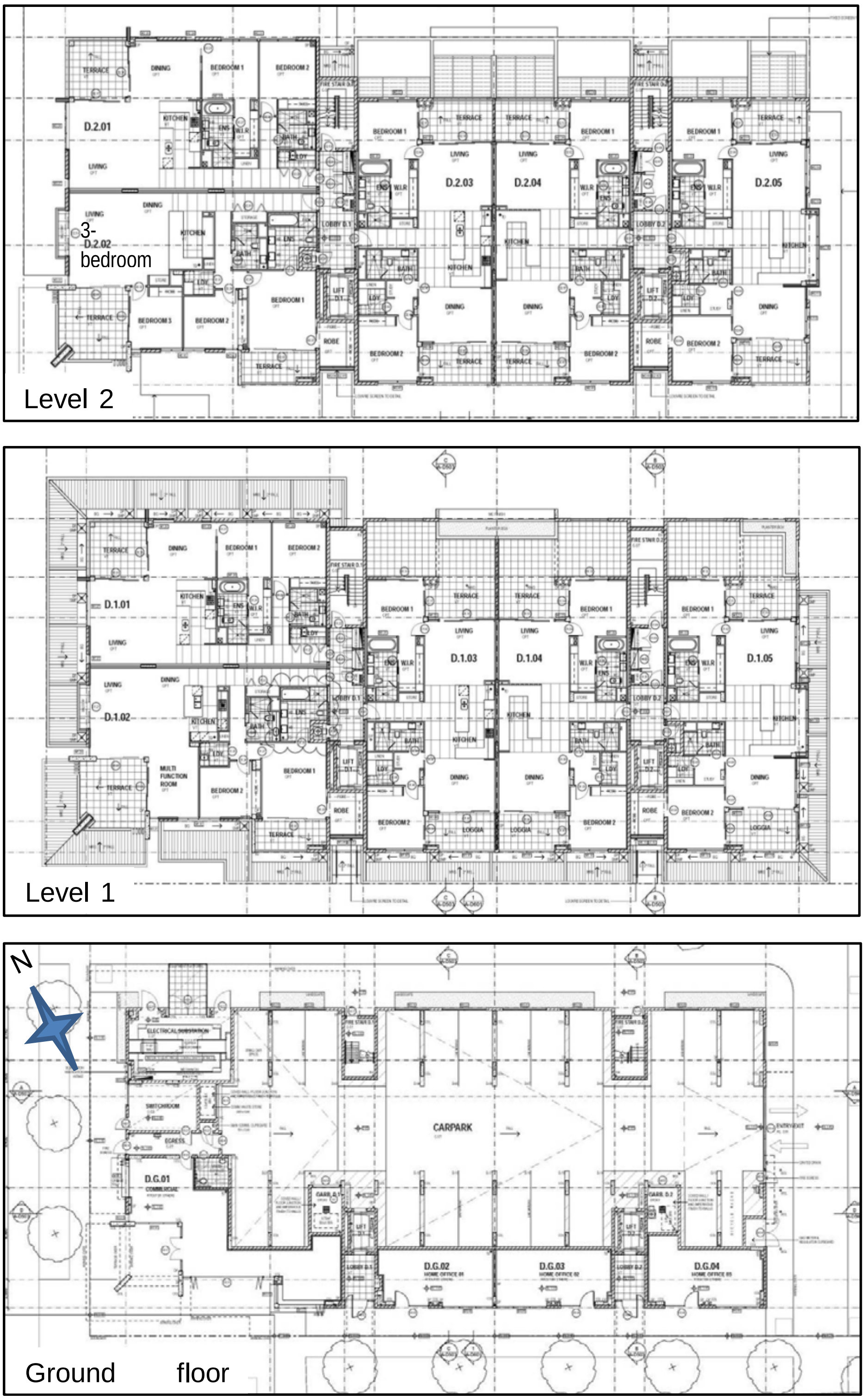


Figure 5.7: Ground, levels 1 and 2 of the low rise apartment building

Source: Floor plans provided by developer, used with permission (not to scale)

The naming convention is ground floor and levels 1 to 4. The ground floor includes three small 36m^2 home offices, a 75 m^2 lettable area and public accessible toilet. The apartments have non-load bearing internal and external walls, except for the inter-unit separating walls and lift/stair well cores. A floor plan of one of the 13 typical 2-bedroom apartments is provided at **Figure 5.8** for comparison purposes with the other cases. The 2-bedroom apartments average 162.3 m^2 gross floor area (GFA), comprising 130 m^2 internal and 32.3 m^2 balcony areas, as indicated in modified case in **Table 5.2.**

Figure 5.8: Level 3 typical two bedroom apartment

Source: Floor plan provided by developer, used with permission (not to scale)

Table 5.2: Modified building configuration for case study B

No. of units	**Apartment type and location in building**	Equiv. bed-rooms	Internal area GFA m ^{2}	External area GFA m ^{2}	Total area GFA m ^{2}
1	2 bedrooms - NW corner	**2**	137	15	152
1	2 bedrooms plus multi room space SW corner	**2**	146	32	178
2	2 bedrooms + separate home office centre	**2**	126	57	183
1	2 bedrooms plus separate home office - E end	**2**	133	58	191
2	2 bedrooms – NW corner	**2**	131	14	145
2	2 bedrooms - centre	**2**	126	25	151
1	2 bedrooms plus study off bed 2 - E end	**2**	133	26	159
2	2 bedrooms - centre	**2**	120	32	152
1	2 bedrooms + attic - E end	**2**	135	33	168
1	3 bedrooms, 2 balconies - NW corner	3	146	32	178
1	*1 storey 3 bedrooms modified - SW corner*	3	146	32	178
15	**2-bedroom apartments average areas:**		**130**	**32.3**	**162.3**

The case building has been modified for the purpose of the analysis by excising the partial fourth level, which contains the main bedroom and bathroom of the penthouse as indicated in Figure 5.6. The reason is to make the building more consistent with conventional three storey residential buildings in the city. The first storey of the penthouse is converted into a 3-bedroom apartment, occupying the same area on level 3 as the 3-bedroom apartment on level 2 below. The minor modification of the data shown in Table 5.3 better maintains the integrity as a three storeys plus ground parking building. The change retains the same number of units and improves the validity of the embodied energy index for the case per m^2 of GFA, without the distortion of a single 4-bedroom dwelling. Penthouse units are a common problem across all cases.

Construction processes

The project developer and the construction prime contractor provided information about the key processes involved in construction of the low rise residential building. The data includes plans and detailed drawings, briefs with specifications and schedules, construction schedules and records, photographic records and interview information. The records used for the thesis are held by Bond University. The details of the process are in section 2.4 of Appendix E. A high level overview is provided here for comparison purposes with the house case. The project is classed as a commercial scale building and is quite different to the domestic scale single storey house. The process involves the following sequences and processes over a 12 month period:

1. **Site preparation and infrastructure**: This operation is a three month process to establish the building pad on the site and install water supply, sewerage, stormwater drainage, electricity (generators), security and lighting.
2. **Substructure**: The ground floor substructure is a two month process involving: minimal excavation for the lift well pits and ground beam, sheet piling around building basement perimeter; piling for footings, sub-floor drainage and plumbing rough-in. The rain water tank is installed. The ground floor concrete slab is then laid with steel reinforcement placement in a continuous pour and finished. The ground floor then becomes a secure storage area and the workspace for trades.
3. **Columns**: Insitu concrete columns are poured to support the upper floors.
4. **Upper floors**: Reinforced floor slabs with beam thickening are laid on a 15 day construction cycle; lift shaft progressive construction and installations at floor landings. Electro-mechanical equipment is progressively installed on each floor fit off. Construction of the upper floors is a three month process and internal construction is simultaneous after the floor above is completed.
5. **Roof**: A steel framed colorbond sheet steel roof is erected over the top level apartments, plant rooms and lift shafts. Once the roof structure is complete, the lifts can be installed and commissioned; in this case over a two month period.
6. **External walls**: Progressive construction of concrete blockwork walls to ground level and upper floors after each floor slab is completed, with installation of windows, and sliding door sets in steel stud framed external walls to balconies. After the roof is completed: rendering and painting of external wall faces,

installation of screens and light fittings over a two month period. When painting is finished, the scaffolding is dismantled from the building.

7. **Internal walls**: Construction progresses for internal stair and lift shaft blockwork and render finish; erection of metal framed partition walls using acoustic insulation and fire-rated plasterboard and fire rated doors.
8. **Air-conditioning, mechanical, electrical and plumbing services**: Progressive rough-in and installation of services to finished floor slabs and external walls are incorporated into apartment fit offs, level by level.
9. **Ceiling finishes**: Plasterboard ceiling linings are fixed to floor slabs and suspended ceilings to accommodate ducted air-conditioning units and duct work; and to conceal plumbing pipework in bathrooms.
10. **Apartment fitout**: The apartment construction and fit off for each floor level takes four–five months involving progressive construction or installation of:
    - internal steel framed stud walls with plasterboard linings and door sets
    - duct screens, wall skirtings and ceiling cornices; pre-paint surfaces
    - kitchen cabinetry, joinery and appliances; laundry and bathroom fixtures and fittings; fitout of robes, shelving and ancillary items; laundry appliances
    - acoustic underlay and ceramic tiling of living area floors and wet area floors and walls; laying of carpet in bedrooms as almost the last activity
    - lighting and electrical fittings and final paint finishes applied to all surfaces.
11. **Ground floor areas**: Common entry foyers, offices and parking area are finished.

5.3.2 Oil and gas inputs

This section records the data inputs for the case and makes brief comments on the findings. The oil and gas input data were assessed from the bill of quantities and supplementary data for the building as the primary unit of analysis. The detailed analysis is in section 4 of Appendix E and spreadsheets in the accompanying CDROM.

Results summary

A summary of estimated embodied energy for the modified case is at **Tables 5.3** and **5.4.** Table 5.3 summarises overall embodied energy. Table 5.4 shows the main inputs, but does not represent a complete estimate of all embodied energy because of unknown energy intensity or difficulty in allocating energy to oil related petrochemicals.

Table 5.3: Summary of embodied energy for modified case B building

Embodied energy (EE) characteristic	As-constructed building	Modified building	Data units
Total embodied energy	63,850.00	62,540.00	GJ
Embodied energy per unit average (15 total)	4,256.67	4,169.33	GJ
Embodied energy per equivalent bedroom average	1,934.85	1,954.38	GJ

Table 5.4: Summary of case B low rise apartment building analysis

Oil related direct input:

Asphalt (minimum) in the adjoining road: 9.5 m^3 (0.63 m^3 per unit)

Oil/gas related indirect input (some partially or not quantified):

Petrochemicals (rounded to nearest unit)	Building	Per unit	Per bedroom
PVC pipes (roadworks drainage only) (m)	55	3.7	1.7
Polyethylene sheet for water/damp-proofing (m^2)	975	56	19
Sealants and paint finishes (area) (m^2)	10,017	668	313
Apartment carpet (m^2)	1,464	35	12
Plumbing – uPVC, HDPE, polybutylene piping	N/A		
PVC electrical cable sheathing	N/A		
Plastics in fire services, mechanical services, lifts	N/A		

* N/A = quantifiable data not available

Estimated embodied energy (GJ):	**Building**	**per unit***	**per bedr'm**	**per m^2**
Total road development materials	362	24	11.31	0.10
Total building materials	56,278	3752	1758.69	14.92
Embodied energy for building and road only	56,640	3776	1770.00	15.02
Household appliances & equipment (ES) approx.	3,000	200	93.75	0.80
Additional allowance for MS, lifts, fire services	2,900	193	90.63	0.77
Total material embodied energy approx. (GJ)	**62,540**	**4,169**	**1,954.38**	**16.59**

* Note: averaged over all 2-bedroom and 3-bedroom units as built

The tables summarise estimated embodied energy of the building with no allowance for site preparation. Table 5.4 shows the total embodied energy from recorded data for the modified building case is estimated to be 62,540 GJ and compares with 63,850 GJ for the as-constructed building. The difference of only about 1,310 GJ (2 per cent) is considered to give confidence to the building modification being a minor change. The spreadsheet CDROM shows the as-constructed data and changes to modify the building configuration. Section 3.2.2 of Appendix E details gaps in the energy input data.

Initial apportionment of embodied energy in Giga Joules (GJ) is on a simple basis averaged over all 15 units; secondly averaged over the total 32 equivalent bedrooms; thirdly averaged on a per m^2 GFA for the modified 3770 m^2 building. These measures take into account the share of common areas on the relevant floor and at ground level. The key indicator is the energy intensity index at 16.59 GJ/m^2 GFA. Each apartment has an allowance of 200 GJ for the appliances, fixtures and small items based on the case A study for consistency. This is used consistently for other cases in the study.

The estimate of oil-based materials and processes in the land development excludes the site bulk earthworks. In that respect the exclusion is comparable to the similar exclusion for the detached house case bulk earthworks due to lack of quantitative data.

Comparison unit embodied energy

On the basis of the modified building, the embodied energy of an average 162.3 m^2 2-bedroom apartment plus 75.4 m^2 as a typical share of common areas (foyers, ground floor areas and parking) to total 237.7 m^2 is **3,943 GJ**. A sensitivity analysis of the modified configuration is in section 3.1.3 of Appendix E. A small discrepancy is caused by the small 75 m^2 commercial area, and a 111 m^2 part of the ground floor that is developed as three home offices, which legally are part of the associated 2-bedroom apartments. These areas are allocated in equal portions to all apartments to maintain the embodied energy integrity of the building. Hence all 15 apartments are allocated 12.4 m^2 of this space (equivalent to 206 GJ per unit).

5.3.3 Analysis of oil inputs findings

This section discusses the oil and gas inputs and notes other key inputs and issues in the case. The study of the low rise apartment building proved to be a more challenging research project than the detached house in establishing the study, but less so in collating and interpreting the large volume of well organised data. The developer provided the complete building file with a descriptive bill of quantities, in 41 detailed spreadsheet pages, which give quantities and unit rates. Yet some components are aggregated without quantification–e.g. roof plumbing, all electrical services and the lifts. As expected, the main materials for the construction are those that were identified in Chapter 3 Table 3.2 as being typical in Australian buildings. This project uses an industry standard approach of a steel reinforced concrete structure.

As in the other cases of the study, the largest direct oil-related input is in the transport of materials and labour to the site and on-site diesel powered plant and equipment include dewatering pumps, concrete pumps and helicopter vibrators used on the concrete floors. This data is omitted due to lack of operating data provided. The direct oil input in the asphalt adjoining roads is less than 1 m^3 per unit. Indirect oil and gas inputs are mainly petrochemicals, as noted in Appendix E section 3.1.2. The energy efficient gas fired water heating and individual apartment air conditioning systems in the building are commonly incorporated components to reduce operational energy consumption.

Key oil and gas inputs

The major structural components in the substructure, columns, stairs, upper floors, (mainly) concrete external walls and roof account for 31,560 GJ (50.4%) of the total embedded energy. Using the MFA analysis in section 3.3 of Chapter 3, the embodied energy components from diesel and gas for the steel and concrete materials and transport of bulk concrete, sand and gravel to the site are set out in **Table 5.5** and total about 2353 GJ. If the energy intensity data indexes are correct, this represents only about 7.5 per cent of the total structural embodied energy.

Table 5.5: Key oil and gas energy inputs in case B low rise apartment building

Oil/Gas	Reinforcing steel		Concrete per unit		Concrete total		Total energy GJ
	Per tonne	Total Tonnes/ GJ	25/32 MPA per m^3	40 MPA per m^3	25/32 MPA m^3/ GJ	40 MPA m^3/ GJ	
Quantities:		203			1194	1196	2390
Diesel GJ	*0.68*	138	*0.178*	*0.179*	212.53	212.89	563.42
Gas GJ	*3.247*	659	*0.332*	*0.484*	396.41	578.86	1634.27
Diesel transport							155
TOTALS GJ	–	864			608.94	791.75	2352.69

Transport of materials and workforce

This type of building relies on more centralised and efficient organisation of the supply chain than detached housing and effectively represents 15 dwellings built in one place simultaneously. The transport of goods and building components is more efficient at this larger building scale. The ground floor parking area provides a convenient and secure temporary storage area, as well as a prefabricating facility. This means deliveries of components, fixtures and fittings can be aggregated at more convenient times and not just supplied piecemeal on a just-in-time ordering basis. This also infers that larger trucks can be used for delivery in a more fuel efficient operation e.g. to deliver a floor full of five apartment kitchen units.

The road haulage of materials and goods is difficult to quantify accurately, partly because of the diverse sources of material supply and the goods distribution networks. All the materials and fittings must be imported through Brisbane and elsewhere to the Gold Coast for manufacture and distribution. In the low rise medium density building, the volume of insitu concrete in the structure amounts to about 2390 m3 (excluding wastage). This represents some 400 transit mixer loads. The contract administrator advised that in a flooring pour, several batching plants all over the Gold Coast will supply 30-40 mixer loads of product to maintain continuity of the process.

The organisation of the workforce is more centralised and efficient at this scale of building, which functions as a virtual manufacturing plant, operating in the completed basement. Most workers prefer to drive to this site even though a bus service is available, partly because the early start times require leaving home well before 7 am.

Conclusions for case B

The case is considered to be representative of an inner urban low rise apartment building of current design in the selected city, with three habitable floors over ground level parking. The design and construction is a conventional sample of the type, with no significant 'green' building features. The conclusion is that the material flow assessment of the case B building provides an adequate basis for comparing the cases.

5.4 Pilot case study C – medium rise apartments

This pilot case study reported in Appendix F investigates a completed six storey apartment building shown in **Figure 5.9** as a medium rise/high density development in the waterfront area of the City of Gold Coast. This project was studied after the case A house in greater detail, due to better information provided by the developer. Hence the spreadsheet data is more elaborate and comprehensive, and forms the model for cases B and D. While the case is not in an inner city location, it meets the criteria in section 2.3 of Appendix A. It fits into the residential typology category C as a four–eight storey medium rise apartment building with lifts, representing the inner city transect. It is considered to be representative of recent large medium rise residential developments in the city and suitable for comparative research with the other cases in the residential typology.

5.4.1 Building information relevant to the case

As noted in section 5.1.2, a detailed description of the case location is problematic, because of the need to maintain anonymity of the development. The case developer is an international construction company with an Australian associate company that uses local consultants for design and construction. This site is similar to other medium rise projects situated in the Broadwater coastal district north of Southport. The site works and building construction are typical of a commercial scale project and are illustrated in the pictures in Figure F.2 of Appendix F. The building is embedded in the complex, hence its nominal land area is 1600 m^2 including 1000 m^2 for equivalent private open space at 22 m^2 per unit. The nominal dwelling density is 280 units per ha.

Figure 5.9: Case study C six storey building viewed from road

Source: The author

Building description

The form of construction is an elongated rectangular shaped steel reinforced concrete structure with a single underground basement, and a sheet steel roof. The 42 as-constructed apartments have non-load bearing internal and external walls, except for the inter-unit separating walls and lift-stair well cores. The apartments are arranged in four sections, each with a separate street access and a small foyer. Each section has a single lift and stair access from the basement to higher floors.

The naming convention is ground floor and levels 1 to 5. The floor plans include a range of 2- to 4-bedroom apartments and a two-storey penthouse that is on one end of the building at levels 4 and 5. Car parking is in the single level basement. Each apartment has at least one parking space with a large three metre wide storage locker. The ground floor includes six apartments, a communal pool and private function room at either end. Levels 1-3 are identical with six 3-bedroom and two 2-bedroom units per level. Level 4 has six 3-bedroom and one 2-bedroom units. Level 5 has five larger apartments, including the upper storey of the penthouse. Representative plans for levels 1 and 5 are shown in **Figure 5.10** and **Table 5.6** shows the apartment configuration. **Two sensitivity tests suggest increasing the yield to 45 units in 6 storeys and basement to reduce the distortion caused by dissimilar unit sizes and improve the validity of results for the purpose of comparison.**

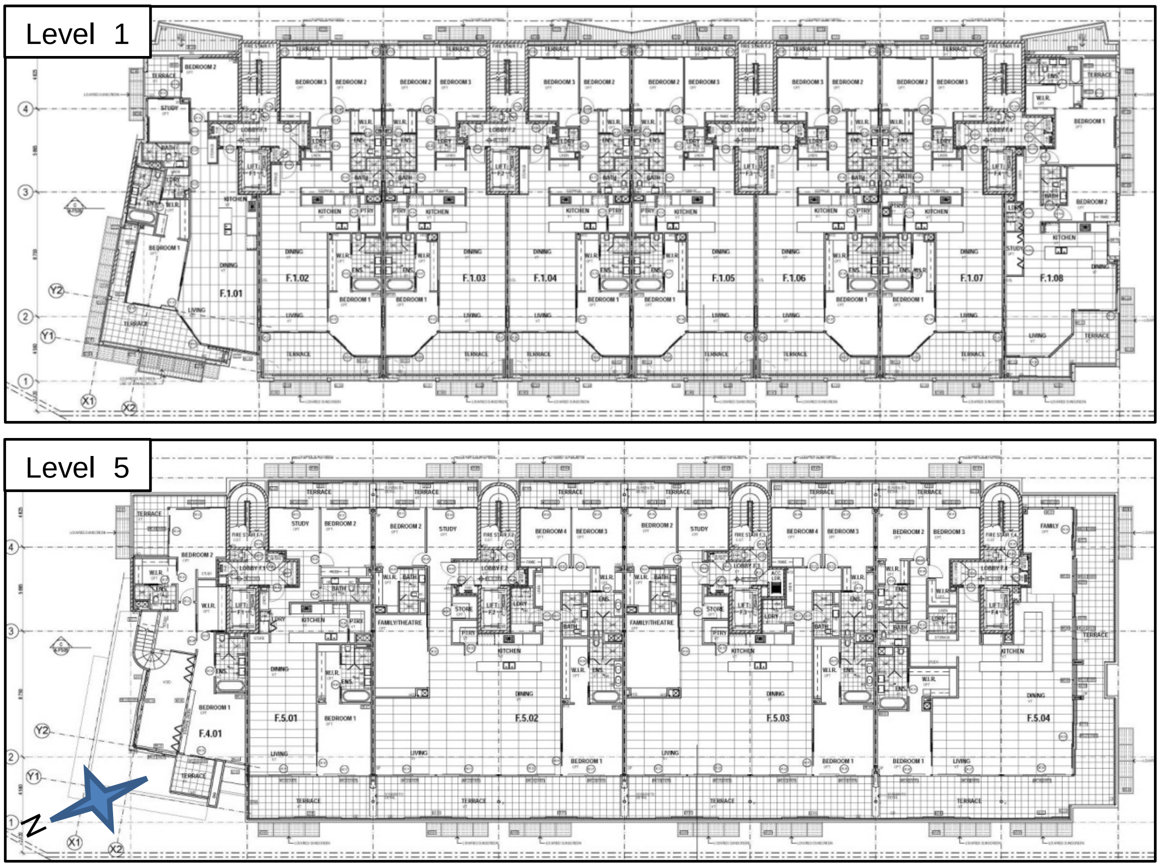


Figure 5.10: Levels 1 and 5 of the six storey apartment building

Source: Floor plans provided by developer, used with permission

Table 5.6: Six storey apartment building configuration

No. of units	Apartment type	Equiv. bedr'm	Internal area GFA m²	External area GFA m²	Total area GFA m²
4	6208, 6308, 6408, 6508 2-bedrooms	2	127	29	156
2	G-6103, 61014 2-bedrooms	2	131	46	177
1	6601 2-bedrooms plus study	3	142	41	183
4	G-6101, 6102, 6105, 6106 3-bedrooms	3	151	43	194
3	6201, 6301, 6401 2-bedrooms plus study	3	137	37	174
4	6202, 6302 , 6402, 6502 3-bedrooms	3	150	32	182
12	6203, 6205, 6303, 6305, 6403, 6405, 6503, 6505, 6207, 6307, 6407, 6507 3-bed	3	151	32	183
8	6204, 6206, 6304, 6306, 6404, 6406, 6504, 6506 3-bed	3	153	32	185
1	2 storey penthouse 3-bedrooms	4	190	83	273
1	6604 3-bedrooms plus family room	4	219	120	339
2	6602, 6603 4-bedrooms plus study plus theatre	6	287	81	368
	3-bedroom apartments average areas:		**147**	**36**	**183.5**

Comparison unit

A floor plan of one of the 28 typical 3-bedroom units is provided at **Figure 5.11.** The average 3-bedroom unit gross floor area is 183 m², comprising 151 m² internal and 32 m² balcony areas. This unit is selected to be the basis for comparison, because it is a similar size to the case A house. The apartment internal construction is similar structurally to the case A house and case B apartments. Internal walls are plasterboard lined metal-stud non-load bearing partitions and ceilings are plasterboard fixed to the concrete slab above. The living areas have tiled floors and the bedrooms are carpeted. While the standard of fixtures and fittings may vary, a similar fitout of room types applies to both the typical apartment and the house and, as well as embodied energy.

Figure 5.11: Level 1 typical three bedroom apartment

Source: Floor plan provided by developer, used with permission

The case building has been subject to a sensitivity test in section 3.2 of Appendix F for the purpose of the analysis comparison unit and embodied energy intensity index.

As indicated in Figure 5.10 and Table 5.6, level 5 includes three large apartments and the penthouse top storey. The ground and other levels also contain smaller 2-bedroom units. Estimation of embodied energy on a simplistic per unit, or per bedroom basis, is distorted by this configuration. Test B replicates a lower level at level 5 and is closer to the original at 14.09 GJ/m^2 and at 3,480 GJ for the comparison unit. It is the preferred result as the more representative data set of 45 units in six levels plus the basement.

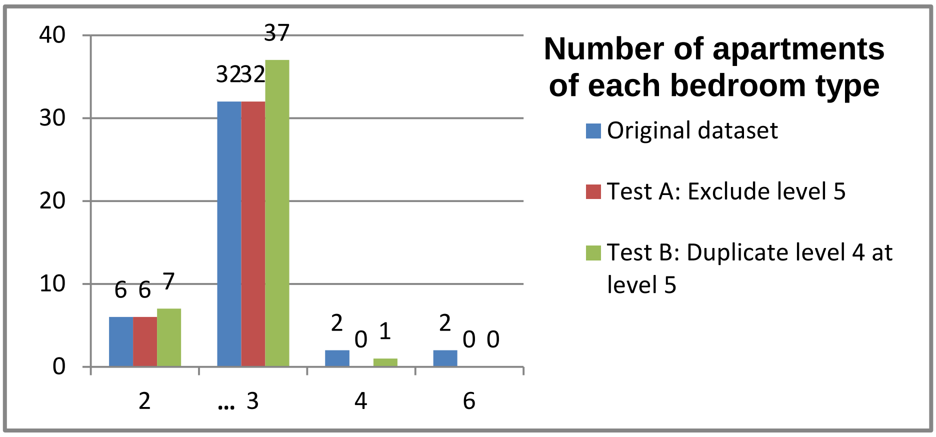


Figure 5.12: Apartment configuration by bedroom type in original and test sets

Construction processes

The project developer and the construction prime contractor provided information about the key processes involved in construction of the six storey residential building. The data includes plans and detailed drawings, briefs with specifications and schedules, construction schedules and records, photographic records and interview information. The records used for the thesis are held by Bond University. The details of the process are in section 2.4 of Appendix F. The project is classed as a commercial scale building and is similar to the low rise apartment building, except that the parking is in a basement rather than ground level. The process therefore involves similar processes over a 12 month period. The main differences are in the substructure and ground floor that includes a swimming pool and a private function room at either end:

Substructure: The single basement substructure is a three month process involving: basement bulk excavation, sheet piling around building basement perimeter; piling for footings, sub-floor drainage and plumbing rough-in, hardcore gravel filling, waterproof membrane, lift pits and ground beam construction, concrete basement slab formwork and reinforcement placement, slab pouring and concrete ramp slab. When constructed, the basement is the workspace and storage area for trades. The basement is finished six months later in the process.

Ground floor areas: Foyers, swimming pool and function room are fitted and finished. These elements are not considered to be important for the purpose of the thesis, although they are important to marketing and apartment lifestyle, depending on the quality.

5.4.2 Oil and gas inputs

This section records the data collection for the case and makes brief comments on the findings in terms of the assumptions and exclusions, and limitations of the analysis. The oil and gas input data were assessed from the bill of quantities and supplementary data for the building as the primary unit of analysis. The detailed analysis is provided in section 3.1 of Appendix F and the spreadsheets in the accompanying CDROM.

Results summary

The summary highlight **Table 5.7** indicates the main inputs, but it underestimates the actual embodied energy, because of unknown energy intensity or difficulty in allocating energy to qualitative data. Initial apportionment of embodied energy is on a simple basis averaged over all 42 as-built units; secondly averaged over the total 124 equivalent bedrooms; thirdly averaged on a per m^2 GFA for the 10,828 m^2 building. The measures apportion a share of common areas on the relevant floor and ground level.

Table 5.7: Summary of case C six storey apartment building analysis

Oil related direct input:

Asphalt (minimum) in the adjoining road: 28.5 m^3 (0.7 m^3 per unit)

Oil/gas related indirect input (some partially or not quantified):

	Building	per unit	per bedroom
Petrochemicals (rounded to nearest unit)			
PVC pipes (roadworks only) (m)	206	5	2
Polyethylene sheet for water/damp-proofing (m^2)	2,349	56	19
Sealants and paint finishes (area) (m^2)	37,672	897	304
Apartment carpet (m^2)	1,464	35	12
Plumbing – uPVC, HDPE, polybutylene piping	N/A		
PVC electrical cable sheathing		N/A	
Plastics in fire services, mechanical services, lifts	N/A		
Kitchen and bathroom cabinets, robe shelving	(Items)		

* N/A = quantifiable data not available

Embodied energy (GJ):	**Building**	**Per unit***	**per bedroom**	**per m^2**
Total road development materials	1,086	26	9	0.10
Total building materials	139,762	3327.7	1,127.0	12.91
Embodied energy for building and road only	140,848	3,353.7	1,136.0	13.01
ES Household appliances & equipment approx.	8,400	200	67.7	0.78
Additional allowance for MS, lifts, fire services	5,002	119	40.3	0.46
Total material embodied energy approx. (GJ)	**154,250**	**3,672.7**	**1,244.0**	**14.25**

* Note: averaged over all units as built

Comparison unit embodied energy

Approximate conservative embodied energy of the building is 154,250 GJ at 14.25 GJ/m^2 GFA. On this basis the embodied energy of a typical 183.5 m^2 3-bedroom/2-bathroom apartment plus about 63.5 m^2 as a typical share of common areas (foyers, pool area, function room and basement) to total 247 m^2 = 3,520 GJ. However, a sensitivity test of the modified building proposes a more representative example. The adjusted embodied energy for a 3-bedroom unit in test B is **3,480 GJ at 14.09 GJ/m^2**. This value is used for the cross-case comparison unit.

5.4.3 Analysis of oil inputs findings

This section summarises the oil and gas inputs detailed in section 4 of Appendix F of the pilot case study. As in case B, the complexity and volume of data in the construction documentation for the six storey building are both a limitation and assistance in the material flow analysis. The data provided by the developer, in the form of the complete building file extends to several hundreds of pages. Yet there are significant gaps in the data, including mechanical and electrical services. As in the other cases, internal piping, electrical cabling and small items are not quantified, including fixings, glues and sealants. The subtleties of oil and gas inputs are therefore easy to lose in the inventory, especially in relation to upstream materials processing. The external works are restricted to road preparation and surfacing in the street adjoining the building for half the road reserve and do not apportion any of the other site roads to the case. While this assumption is not an accurate reflection of the whole site environment, it is comparable to the other cases and would be representative of an apartment building located in a normal street situation, e.g. as infill development.

Increasing the density of apartments reduces the embodied energy per dwelling by making more efficient use of the common areas and basement parking. This would be a preferred result, but is dependent upon a market willing to pay a premium for smaller three bedroom units rather than the usual penthouses at the highest level of the building (and where most profit is made by the developer). Yet this finding points toward a higher building as being more energy efficient, providing the dwelling size is modest. What has not been considered is the significance of the actual or potential number of occupants. This is analysed in the cross-case comparison in section 5.6.

Key oil and gas inputs

The major structural components in the substructure, columns, stairs, upper floors, (mainly) concrete walls and roof account for 95,376 GJ (61.8%) of the total structural embodied energy. Using the MFA analysis in section 3.3 of Chapter 3, the embodied energy components from diesel and gas for the steel and concrete materials and transport of bulk concrete, sand and gravel to the site are set out in **Table 5.8** and total 5868.36 GJ. If the energy intensity data indexes are correct, this represents only about 6.1 per cent of the total structural embodied energy.

Table 5.8: Oil and gas energy inputs in steel reinforced concrete 6 storey building

Oil/Gas	Reinforcing steel		Concrete per unit		Concrete total		Total energy GJ
	Per tonne	Total tonnes	25/32 MPA per m³	40 MPA per m³	25/32 MPA m³	40 MPA m³	
Quantities:		432.30			2971.72	3327.40	
Diesel GJ	*0.68*	294.00	*0.178*	*0.179*	528.97	595.60	1418.57
Gas GJ	*3.247*	1403.70	*0.332*	*0.484*	986.61	1610.48	4000.79
Diesel transport Bulk supplies							449.0
TOTALS GJ		1697.70			1515.58	2206.08	5868.36

Transport of materials and workforce

As in the other cases of the study, the largest direct oil-related input is in the transport of materials and labour to the site. This type of building relies on more centralised and efficient organisation of the supply chain than detached housing and effectively represents 42 (equivalent 45) dwellings built in one place simultaneously. The road haulage of materials and goods is an important aspect of the construction that is difficult to quantify accurately, partly because of the diverse sources of material supply and the goods distribution networks from Brisbane and elsewhere to the Gold Coast. The deceptively small apparent transport related energy—e.g. for insitu concrete, sand and gravel at 450 GJ—is therefore not the whole story in examining the possible oil-related impacts in a future oil constrained scenario. In the medium rise building, the volume of insitu concrete in the structure amounts to about 7165 m3 (excluding wastage). This represents some 1200 transit mixer loads. Each flooring pour relies on several batching plants all over the Gold Coast to supply 65-75 mixer loads of product to maintain continuity of the process.

As in case B, the organisation of the construction workforce is also more centralised and efficient at this commercial scale of building. This type of building functions as a virtual manufacturing plant, operating in the completed basement. Most workers still prefer to drive to the site. This preference is strongly held even though a bus service is close to the site, partly because of the need to leave home well before 7 am. It is suggested that such commuting practices could change more easily in the future for this scale of building as infill in development corridors.

Conclusions for case C

The case is considered to be representative of an inner urban medium rise apartment building, both in the selected city and more generally in all Australian major cities. Although additional research is recommended, the conclusion is that the material flow assessment of the six storey building for oil and gas inputs provides an adequate basis for comparing cases. It should be noted each unit includes a share of common area.

5.5 Pilot case study D – high rise apartment tower

This pilot case study reported in Appendix G investigates a completed 31 storey, 170 apartment tower shown in Figure 5.13 as a high rise, high density case in the waterfront area of the City of Gold Coast. This was the last project analysed in the study and has the advantage of the learning gained from analysing the other cases. **The case analysis again has modified the configuration by excising one level and replicating level 30 at the top penthouse level to make it 30 storeys to improve analysis.** It is in an inner city location and meets the criteria in Appendix A, section 2.3 and fits into the residential typology category D as a high rise, high density apartment building with lifts, representing the inner and central city transect.

Figure 5.13: Case study D 30 storey building viewed from road

Source: Photo by the author

5.5.1 Building information relevant to the case

As noted in section 5.1.2, a detailed text and photographic description of the high rise case is problematic, if not impracticable, because of the anonymity requirements for participants. The case developer is an Australia-wide residential construction company. The building operations are custom designed projects that are tailored to specific site conditions and architectural requirements to meet the market demand. The case is a residential building with resort style amenities, which is typical of the iconic style of similar residential towers in Surfers Paradise by the same and other developers.

The building is a tall rectangular shaped structure, and is considered to be representative of recent high rise/high density residential developments in the city. The building is an isolated structure as part of the Surfers Paradise city of towers. It occupies a site of 2673 m2 and the as-constructed 32 storey configuration has 170 dwelling units. This is a density of 636 dwellings (or 853 actual bedrooms) per net hectare, which is above the highest RD8 category in the planning scheme noted in Table 4.1. Approval was subject to compliance with plot ratio controls and justification of the design merits under the special Surfers Paradise planning provisions. The site coverage of the tower at 720 m^2 is 27 per cent of the site; comparable to a large house lot. Total indoor area for apartments and common areas is 21,327 m^2, excluding 3-level basements. The modified total bedrooms is equivalent to 57 case A 4-bedroom houses.

The data provided by the developer and the photo in Figure G.2 indicate that the form of construction is a steel reinforced concrete structure with a three underground basement levels, and a sheet steel roof. The naming convention is for the ground floor to be level 1. The building has three storeys of a smaller footprint sitting on the basement podium. The building is served by three lifts and scissor (dual) fire stair access. The small 472 m^2 Level 3 contains four 1-bedroom apartments. The apartments on the larger 710 m^2 typical levels 4-30 shown in **Figure 5.14** are arranged as six per floor in two mirrored sections around the core, comprising two 1-bedroom, two 1-bedroom plus internal study alcove (counted just as 1 bedroom), and two 2-bedroom apartments. The building includes three large 3-bedroom penthouses at Level 31. Car parking is in three basement levels providing 184 resident and 20 visitor parking spaces. Most apartments have one parking space with 14 extra spaces allocated to higher and larger units. In comparison with the 130 m^2 internal area 2-bedroom apartments in case B, the high rise apartments are smaller in internal area, and only one third of them are the 2-bedroom layout used as comparison unit.

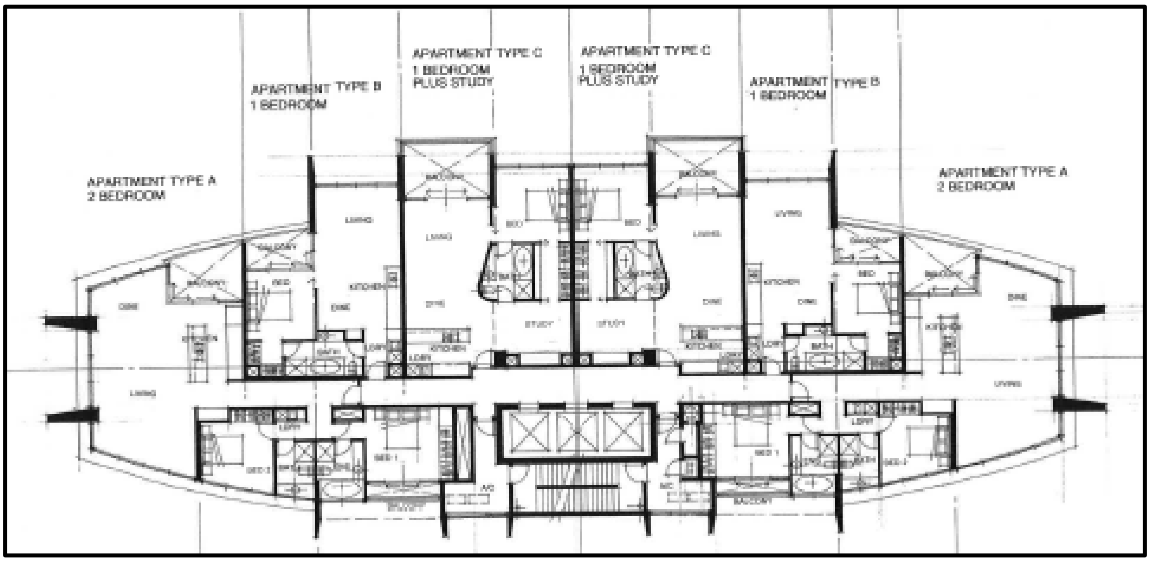


Figure 5.14: Typical levels 4-30 apartment floor plan layout

Source: Floor plans provided by developer, used with permission

Building modification

The research has endeavoured in other cases to focus on what would be regarded as a typical dwelling unit for the purposes of comparison. For example the case C six storey apartment building configuration was modified to replace the penthouse level with mainly 3-bedroom units. **Table 5.9** shows two configurations: the as-built and a slightly modified version for the purpose of analysis. The building has been modified by excising the small Level 2 (472 m^2) amenities floor that includes the manager's 2-bedroom apartment; and converting the penthouse level to a typical level with six apartments as in Figure 5.14. This has the effect of reducing the non-residential areas to just the ground level and replicating the top level 31 internal layout. The latter change overcomes the aberration of having just 3 large apartments in the building. These modifications are similar to the six storey building, but the tower retains more unit diversity. A floor plan of one of the typical largest 2-bedroom units (at modified levels 4-30) is provided at **Figure 5.15** for comparison purposes with the other cases. The gross floor area is 123.8 m^2, comprising 112 m^2 internal and 11.8 m^2 balcony areas.

Table 5.9: High rise apartment tower configuration

Building configuration:	**Storeys**	**Number of bedroom/study units**					
		1	**1 + 1**	**2**	**3**	**Total units**	**Total bedr'm**
As-built building (including penthouse levels and 2-bedroom manager unit)	31+ roof	56	56	55	3	170	225
Modified for analysis (excise penthouse levels and manager 2-bedroom unit)	30	58	58	56	0	172	228

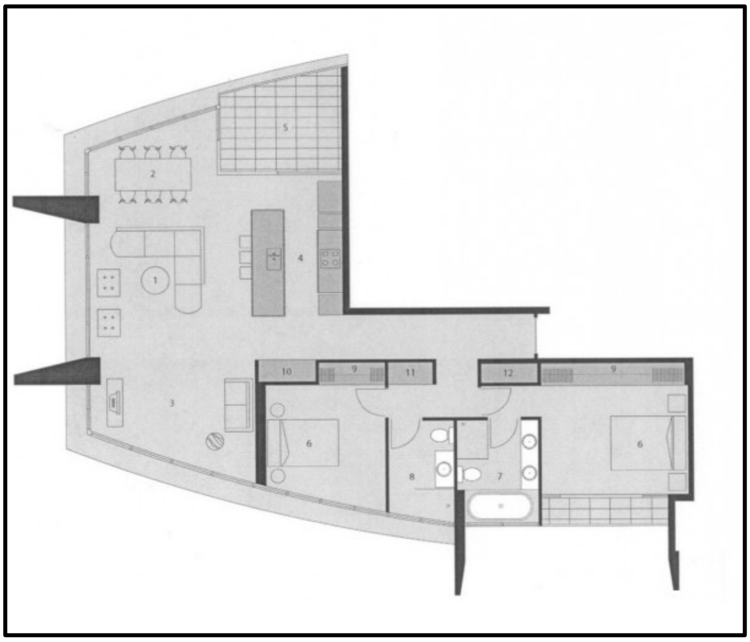


Figure 5.15: 2-bedroom comparison apartment floor plan

Source: Floor plans provided by developer, used with permission

Construction processes

This section outlines the key processes involved in construction of the high rise residential building described in section 2.4 of Appendix G. The aim is to highlight the differences in the processes between this high rise tower and the six storey apartment building outlined in section 5.4.1. Information for this description was provided by the project developer, including plans and detailed drawings, briefs with specifications and schedules, construction records, photographic record and interview information. The main differences are in the 3-basement substructure; ground floor that includes an external podium swimming pool; and a tower superstructure with lifts in the core:

1. **Essential temporary and permanent site infrastructure**: Water supply, sewerage, stormwater drainage, electricity supply and telecommunications cabling are already in place to service the infill site.

2. **Substructure**: The site construction set-out includes the building basement footprint just within the site boundaries. The triple basement substructure is a six month process involving: basement bulk excavation, sheet piling around building basement perimeter; piling for footings, sub-floor drainage, lift pits construction, concrete basement slab formwork and reinforcement placement, slab pouring and finishing. Site dewatering is a constant requirement until the basements are completed and the ground surface reinstated. When constructed, the upper slab becomes the exposed podium of the development. The basement is used for the workspace and storage area for trades. The external swimming pool is constructed as part of the basement podium slab and finished off later.

3. **Columns**: Insitu concrete columns are poured to support the upper floors and are more substantial and stronger (60MPa) to carry the extra weight of the 30 storeys.

4. **Superstructure**: The whole tower building is more solidly built. Reinforced floor slabs with beam thickening are laid on a five day construction cycle: slab formwork and reinforcement placement, slab pouring, levelling and finishing; emergency staircase construction, using similar process to floor slabs. The lift shaft is integrated into the core with installations at floor landings. The jump-form is progressively raised at each floor level. Progressive electro-mechanical equipment installation is undertaken on each floor fit off, with installation of external balustrades and handrails.

5. **External walls**: External walls are 300 mm concrete. Progressive construction of fixed curtain window walls between slabs of upper floors occurs after each floor slab is completed; fixing of sunhoods, balustrades and handrails to balconies. Foyer doors and fire doors are installed progressively.

6. **Air-conditioning, mechanical, electrical and plumbing services**: Progressive rough-in and fit-off installation of services occurs to finished floor slabs; level by level incorporated into apartment fit offs. Plasterboard linings to suspended

ceilings accommodate ducted air-conditioning units and duct work, or conceal plumbing pipework in bathrooms.

7. **Apartment fitout**: The apartment construction and fit off for each floor level takes about five months. It is similar to the six storey apartment building involving: progressive erection of internal steel framed stud walls with plasterboard linings; installation of kitchen cabinetry, joinery and appliances; laundry and bathroom fixtures and fittings; fitout of robes, shelving and ancillary items. Acoustic underlay and ceramic tiling of living area floors and wet area floors and walls. Installation of lighting and electrical fittings. Final paint and wallpaper finishes applied to all surfaces. Fitting of robe sliding mirror doors and internal window treatments provided by developer. Laying of carpet in living areas and bedrooms is almost the last activity. Installation of laundry appliances (washers and dryers).

5.5.2 Oil and gas inputs

This section records the data collection for the case and makes brief comments on the findings in terms of the assumptions and exclusions, and limitations of the analysis. The oil and gas input data were assessed from the provided pre-tender bill of quantities and supplementary data for the building. The detailed analysis is provided in section 3.1 of Appendix G and the spreadsheets in the accompanying CDROM.

Results summary

The summary highlight **Table 5.10** indicates the main inputs, but it underestimates the actual embodied energy, because of unknown energy intensity or difficulty in allocating energy to qualitative data—e.g. the complete absence of data for substructure piling, etc., below the lowest basement. The CDROM spreadsheet shows the as-constructed data and changes to modify the building configuration. Initial apportionment of embodied energy in Giga Joules (GJ) is on a simple basis averaged over all 172 units; secondly averaged over the total 228 equivalent bedrooms where appropriate; thirdly averaged on a per m^2 GFA for the 28,302 m^2 building. These measures all take into account the share of common areas on the relevant floor level, ground level and the three basement levels. These results are for the modified building configuration that improves the validity of the results for comparison purposes.

A typical apartment analysis was undertaken in section 3.1.3 of Appendix G to focus on what would be regarded as a typical dwelling unit for the purposes of comparison. In this case, the tower has a more consistent floor plan that is repeated over 27 levels with just three unit designs. The preferred ‘typical’ apartment is a 2-bedroom type of a similar area to the other cases, but which only comprise one third of all the apartments. In reality the mixed diversity of unit sizes in the tower case is more typical of this high density building type in the Gold Coast context. The aim of the case study is to test the range of apartments for the cross-case comparison.

Table 5.10: Summary of case D 30 storey apartment tower analysis

Oil related direct input:
Asphalt (minimum) in adjoining road (from Case B):9.5 m^3 (0.055 m^3 per unit)

Oil/gas related indirect input (some partially or not quantified):

Petrochemicals:	Building	Per unit	Per bedroom	
PVC pipes (roadworks only) (from Case B)	55	0.3	0.2	m
Polyethylene sheet for water/damp-proofing	9,300	54.1	40.8	m^2
Sealants and paint finishes (area)	80,336	467.1	352.4	m^2
Apartment carpet (includes corridors carpet)	13,719	79.2	--	m^2
Plumbing – uPVC, HDPE, polybutylene piping	N/A*			
PVC electrical cable sheathing	N/A*			
Plastics in Fire services, mechanical services, lifts	N/A*			

* N/A = quantifiable data not available

Embodied energy:	GJ per Building	GJ per unit*	GJ per bedr'm	GJ per m^2
Total road development materials (Case B)	362	2.10	1.59	0.01
Total building materials	446,599	2,596.51	1,958.77	15.78
Embodied energy for building and road only	446,961	2,598.61	1960.36	15.79
Additional allowance for lifts and fire services	20,000	116.28	87.72	0.71
Total material embodied energy approx.	**466,961**	**2,714.92,048.116.50**		

* Note: averaged over all units as built

Comparison unit embodied energy

The raw average unit embodied energy is 2715 GJ. The approximate conservative embodied energy of building and adjoining road (half width) is 16.50 GJ per m^2 GFA. **Table 5.11** shows an allocation of common areas and the embodied energy of each apartment type, which modifies the average embodied energy in Table 5.10 to a higher value of 3075 GJ at 16.50 GJ per m^2 GFA to use as the comparison 2-bedroom unit.

Table 5.11: Allocation of common areas to case D apartments

Building allocation areas	**Total of each common area m^2**	**Total share of area: 1/6 of core area 1/172 other areas**	**Total area allocated to apartment by type**		
			1	**1+1**	**2**
Apartment area (including balcony areas)			63.1	86.5	123.8
Core area at each level	102	17.0			
3 Basement levels	6975	40.55			
Ground level common area	761	4.42			
Roof terrace common area	107	0.62			
Average share of common areas		**62.6**	62.6	62.6	62.6
Allocated apartment areas:			**125.7**	**149.1**	**186.4**
Embodied energy per apartment based on the building value of 16.50 GJ per m^2			**2074**	**2460**	**3075**

5.5.3 Analysis of oil inputs findings

This section summarises the oil and gas inputs detailed in section 4 of Appendix G of the pilot case study. The plans and other information are not as detailed as the case B and C documentation. The cost plan bill of quantities and the plans are the primary sources of data used in the analysis. In the Australian context this high rise tower form of development is the most complex construction project undertaking. The repetitious nature of floor pouring and fit off is reasonably straightforward (project manager pers. Comm. 1 March 2013). Obvious gaps in the data noted above include the complete absence of data for substructure piling, etc., below the lowest basement, which is mainly concrete and sheet steel piling. The absence of any data on hydraulic, mechanical, lift and electrical services is similar to the three and six storey cases. The external works are restricted to road repair and resurfacing in the access street adjoining the building for half the road width. The advantage of an infill site development is that the power is available from commencement and this project did not experience the delays of the greenfield cases in connection. No data records are available on the actual power consumption, however, the main electricity supply relies on coal fired power stations and is not relevant to this thesis. Allowing for these limitations, the archival qualitative and quantitative data provided by the developer are adequate for the basic purpose of the pilot case material flow analysis.

Key oil and gas inputs

As expected from cases B and C, the main materials for the construction are those that were identified in Chapter 3 Table 3.2 as being typical in Australian buildings. This project uses an industry standard approach for high rise construction of a steel reinforced concrete structure and a combination of poured concrete, limited concrete block and mainly window walls. The major structural components in the substructure, columns, stairs, upper floors, (mainly) concrete walls and roof account for 333,492 GJ (71.4%) of the 466,961 GJ total embodied energy. This proportion is very close to the six storey value (72.5%). Using the MFA analysis in section 3.3 of Chapter 3, the embodied energy components from diesel and gas for steel and bulk concrete materials, concrete block walls, plus an additional allowance for transport of bulk concrete, sand and gravel to the site are set out in **Table 5.12** and total 16,424.6 GJ. This calculation excludes the oil and gas inputs into the external window walls and sliding doors (9396 m^2) and the non-load bearing metal frame internal partition walls (8694 m^2). The oil and gas embodied energy is 648 GJ for the glass and 56 GJ for the steel. These additions increase the oil and gas embodied energy to about 17,130 GJ, which is a minimum of 5.1 per cent of the total structure. The recorded oil and gas component does not account for all the other unknown transport distribution elements that are excluded from this calculation.

Table 5.12: Oil and gas energy inputs in steel reinforced concrete 30 storey building

Oil/Gas	Reinforcing steel		Concrete per unit			Concrete total				Total energy GJ
	Per tonne	Total tonnes	32 MPA per m^3	40 MPA per m^3	60 MPA per m^3	Block form m^3	32 MPA m^3	40 MPA m^3	60 MPA m^3	
Quantities:		1893.0				2200	8247	3448	576	
Diesel GJ:	*0.68*	1287.2	*0.178*	*0.179*	*0.182*	391.6	1468.0	617.2	104.8	3868.8
Gas GJ:	*3.247*	6146.6	*0.332*	*0.484*	*0.934*	730.4	2738.0	1668.8	538.0	11821.8
Diesel transport total concrete										734.0
TOTALS GJ		7433.8					4206.0	2286.0	642.8	16424.6

Transport of materials and workforce

As in the other cases of the study, the largest direct oil-related input is in the transport of materials and labour to the site. This type of building relies on more centralised and efficient organisation of the supply chain than detached housing and effectively constructs 170 small dwellings (as-built) in a large house lot footprint simultaneously. Moreover, the central city location exacerbates the transport problems in at least two ways–by a longer supply chain and through a more congested part of the road system.

While each concrete floor pour is smaller than for the six storey building with twice the footprint, the total quantity at 12,270 m^3 is some 72 per cent more than the 7165 m^3 of the medium rise building. The nearest concrete batching plant is assumed to be at Worongary quarry, about 16 km from the site (a similar distance to case C).

The high rise building as an infill development in a central city location offers the most opportunity for the workforce to use shared or public transport to commute to work. In this case a frequent bus service passes the site. A survey of public transport usage was not possible for the completed building, but is a useful research project.

Conclusions for case D

The case is considered to be representative of a central urban high rise apartment building, both in the selected city and more generally in all Australian major cities. The design and construction is considered to be a conventional sample of the type, with no significant 'green' building features. The total area for apartments and common areas (excluding basements) is 21,327 m^2; equivalent in total bedrooms to some 57 case A 4-bedroom houses on a single detached house lot footprint. The tentative conclusion is that a taller building may have less embodied energy, providing the dwelling size is modest. Clearly the tower design relies on a market willing to pay a premium for smaller two bedroom units in a central city environment. The overall conclusion is that the material flow assessment of the 30 storey apartment tower for oil and gas inputs provides an adequate basis for comparing with the other cases.

5.6 Cross-case comparison

The aim in analysing the case study data is to determine the relative impact of oil inputs on each dwelling category. It is expected that there will be some differences between various types of buildings and their associated development settings. An inductive approach collates the data sets and performs analysis to create and compare vulnerability indices of these sample cases as a representative model for each category of building type. The test is to determine the degree of significance to a reasonable confidence level. If one or more case scenarios show a significantly different vulnerability – e.g. medium rise/high density development, this result would be a potential indicator for redirecting planning strategies and appropriate zoning densities towards that type of development. While that may be regarded as a simplistic outcome of the research, it is not expected to be so clear cut, because of the complexities of oil related dependencies. These are likely to highlight some significant problems with *all* types of development. Neither does the comparison compare like with like in terms of living space, number of bedrooms, or residential pricing factors of land and buildings.

The cross-case comparison draws on the summarised information and tabulated data in sections 5.2 to 5.5 for each case to explore the differences that may achieve the aim. The estimation of embodied energy is one of the key indicators used in life cycle analysis. The recorded embodied energy is therefore the obvious starting point for the cross-case comparative analysis in this study. The initial comparison is between the reference house and the apartment cases. This leads to analysis of the energy intensity indices and considers the influence of occupancy rates on the calculated results that modify the initial conclusions. A comparative summary is then made of the oil and gas inputs and the construction processes. Lastly some common issues are addressed, including transport and on-site energy.

5.6.1 Embodied energy comparisons

Table 5.13 compares the estimated energy in the four cases, using the reference case A house as the base index 100.0. **Figure 5.16** shows the comparison of embodied energy and energy intensity indices between the cases in graphical form. **Figure 5.17** illustrates the selected embodied energy intensities indexed to the case A house. The initial comparison is made between the apartment buildings and the reference house.

Reference case detached house embodied energy

Initial inferences are drawn between the three apartment buildings and the reference case study A 4-bedroom (equivalent) house on a 570 m^2 lot. It has 132 m^2 internal area (148 m^2 with outdoor covered areas) and 185 m^2 GFA under the roof including garage. The house has a total 2818 GJ embodied energy at 15.23 GJ/m^2, not taking into account gaps in the material input data for plumbing, electrical wiring and air-conditioning. In each apartment building case an allowance is added for the missing mechanical and electrical services, and for unit fitout to make it more equivalent to the house.

Table 5.13: Case study types: comparison of recorded embodied energy

Characteristic	Case A: detached house	Case B: 3/4 storey low rise units		Case C: 6 storey medium rise units		Case D: 30 storey high rise units	
		Description	data	Description	data	Description	data
No of storeys as analysed	1		3		6		30
Parking arrangements	Internal double garage	Secure internal ground level parking		1 basement level		3 basement levels	
Total dwelling units as analysed	1		15		45		172
Total number of equivalent bedrooms based on typical unit	4	2-bed unit	13	37 typical 3-bed units	111	2-bedroom 56 units	112
Total number of equivalent bedrooms secondary unit		3-bed	2	7 2-bed units	14	1+1 bedroom 58 units	58
Total number of equivalent bedrooms other units				penthouse 3-bed unit	3	1-bedroom 58 units	58
Total bedrooms	**4**		**32**		**128**		**228**
Total building area m2 GFA	185.0		3,770.0		11,016.0		28,302.0
Comparison unit:							
Average internal area m2 GFA	132.0		130.0		147.0	2-bed unit	112.0
Average external area m2	17.0		32.3		36.0	2-bed unit	11.8
Average total unit area m2	149.0		162.3		183.5	2-bed unit	123.8
Average common/parking area allocation m2	36.0		75.4		63.5		62.6
Average total area m^2	**185.0**		**237.7**		**247.0**		**186.4**
Embodied energy for building	2,818		62,540		155,204		466,961
Total building Embodied energy per m^2	**15.23**		**16.59**		**14.09**		**16.50**
Embodied energy analysed unit	**2,818**		**3,943**		**3,480**		**3,075**
Embodied energy per bedroom	704.5		1,971.6		1,160.0		1,537.7
Typical occupancy for type	4		2		3.0		1.5
Embodied energy per typical occupant for typical unit	**704.5**		**1,971.6**		**1,160.0**		**2,050.3**
Statistical occupancy in area	3.0		1.85		2.1		1.3
Embodied energy per statistical occupant	**939.33**		**2,131.4**		**1,657.1**		**2,365.7**
EMBODIED ENERGY INDEX - based on EE/m^2 total area	**100.0**		**108.9**		**92.5**		**108.3**
EMBODIED ENERGY INDEX - per equivalent bedroom	**100.0**		**279.9**		**164.7**		**218.3**
EMBODIED ENERGY INDEX - per typical occupant	**100.0**		**279.9**		**164.7**		**291.0**
EMBODIED ENERGY INDEX - per statistical occupant	**100.0**		**226.9**		**176.4**		**251.9**

Notes:

1. The house study estimates have the advantage of comparison with a similar house study in Melbourne that attributed direct energy inputs from ABS statistics. These were added to the raw data to give a more accurate estimate than was achieved for the other cases.
2. The indices are only a partially indicative measure because of gaps in the provided data. This means the embodied energy for cases B-D are underestimated in the table and in the indices.
3. Two occupancy factors are for ‘typical’ or design occupancy, based on the characteristics for each type of comparison dwelling; and for ‘statistical’ values provided by Gold Coast City.

Low rise apartment building comparison

The recorded embodied energy of the low rise apartment building is 62,540 GJ at an average of 16.59 GJ/m^2 GFA, which is larger than the house, even with gaps in the material input data. This difference could not be explained by the economies of the building design having lateral and vertical attachment of the 32 dwelling units. However, at the dwelling unit scale, the nominal 162.3 m^2 2-bedroom apartment has a 10 per cent larger area and greater 3943 GJ (extra 40%) embodied energy. This is partly due to each apartment having more concrete, and a 64.7 m^2 overhead of shared common area building fabric for access and parking, compared to the 37 m^2 house garage, It also has a 10.7 m^2 share of three small home offices and a commercial area. In addition to the built-in amenities, they also share the outdoor common areas in the development site. Neither case has assessed the embodied energy of outdoor facilities.

Medium rise apartment building comparison

The recorded embodied energy of the six storey apartment building is 155,204 GJ at 14.09 GJ/m^2, which is less than the house, albeit with gaps in the material input data. This difference could partly be explained in the economies of the building design having lateral and vertical attachment of the 45 dwelling units. At the dwelling unit scale, the nominal 183.5 m^2 3-bedroom apartment has a 23 per cent larger area and 3480 GJ (a similar extra 23.5%) embodied energy. However, this total energy includes the extra 66.5 m^2 (36%) overhead for each apartment of shared common area building fabric for access, parking and facilities, including an indoor swimming pool. In addition to the built-in amenities, they also share the outdoor common areas in the development site. Neither case has assessed the embodied energy of outdoor facilities.

High rise apartment building comparison

The recorded embodied energy of the 30 storey apartment building is 466,961 GJ at 16.50 GJ/m^2, which is slightly more than the house, but with gaps in the material input data. This difference could mainly be explained in the economies of the building design having lateral and vertical attachment of the 172 dwelling units. At the dwelling unit scale, the largest size nominal 123.8 m^2 2-bedroom apartment has 17 per cent less area, but slightly greater 3075 GJ (extra 9%) embodied energy. This is because each apartment has an extra 62.6 m^2 (50.5%) overhead of shared common area building fabric for access, parking and facilities, including an outdoor swimming pool. They also share the outdoor common areas of the development site. The apartment case has not assessed the embodied energy of other outdoor facilities beyond the podium slab.

Embodied energy indices comparison

The graphs in Figures 5.16 and 5.17 compare the embodied energy of the nominated comparison dwelling units and include three selected characteristics relating to the energy per bedroom, the number of 'typical' occupants and the 'statistical' occupants.

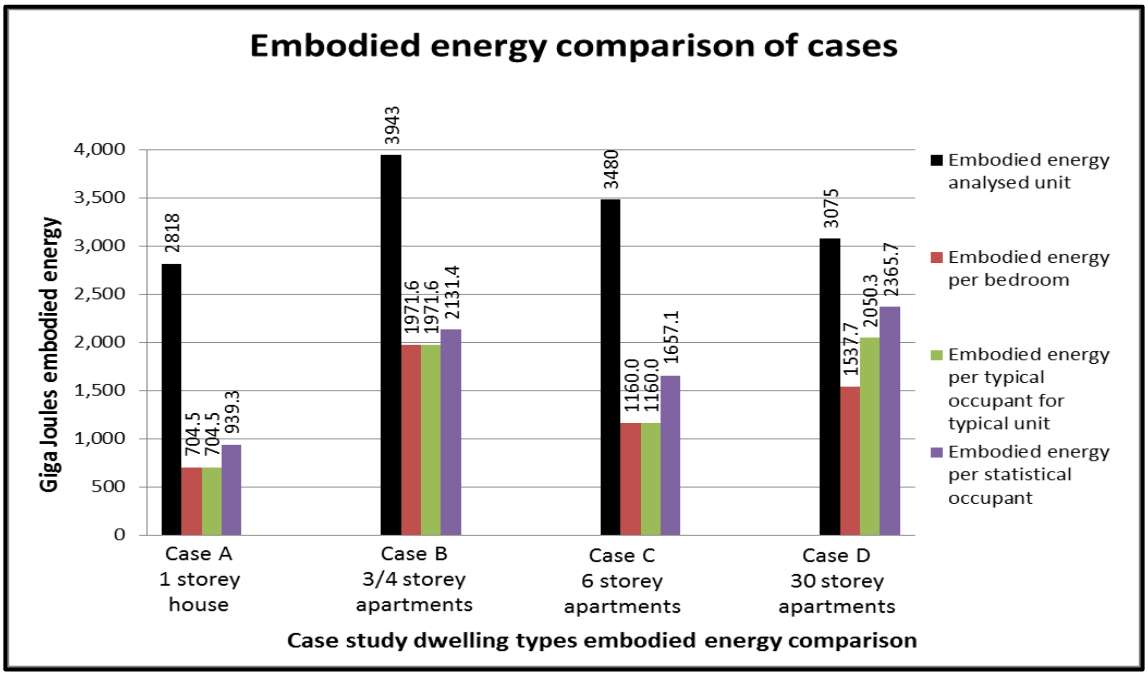


Figure 5.16: Embodied energy results for cross-case comparison

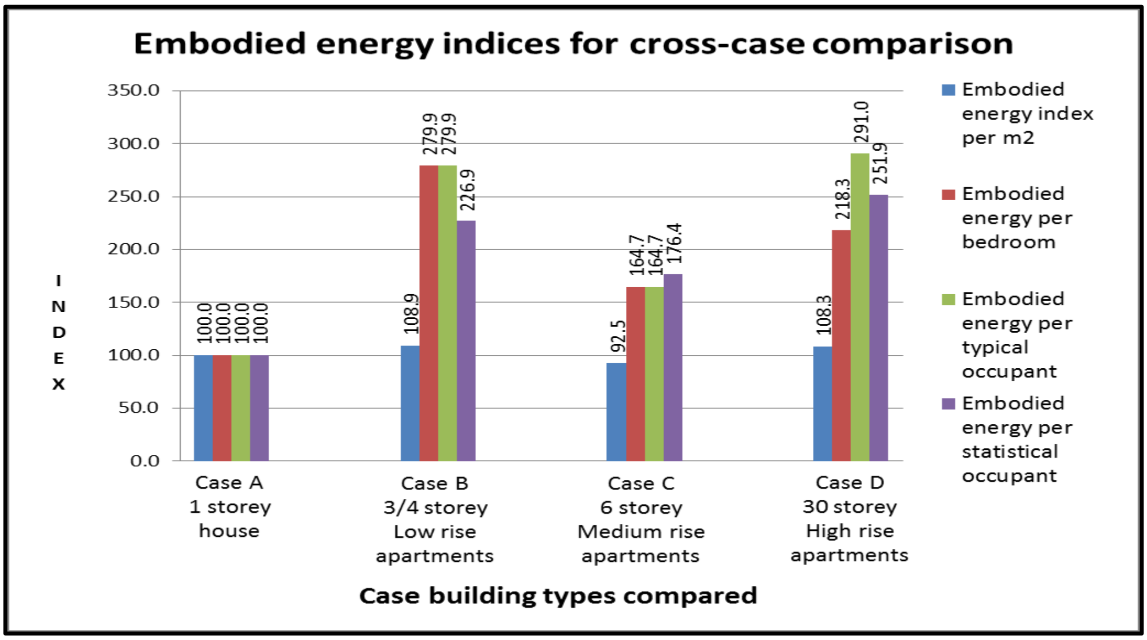


Figure 5.17: Embodied energy indices for cross-case comparison

Two occupancy rates are used: a 'typical' value and a statistical value. The typical value is suggested as a 'design' occupancy based on the likely ultimate whole person number:

a. The 3-bedroom plus study house represents a family home for two parents and two children, totalling four persons. A larger number of children could be used, but the statistical evidence does not support it as the Gold Coast suburban average household size is only 2.8 and the Coomera district is 3.0 (Gold Coast City 2013).

b. The 2-bedroom low rise apartment represents an inner urban style home for a couple, or two share mates. It could also be a small dwelling for a single parent or a retired couple.

c. The 3-bedroom apartment represents a home for a couple and with either one child or a share-mate; or three share-mates. More occupants are not justified by the statistical averages in the sources noted below.

d. The 2-bedroom high rise apartment represents a central urban style home for an even mix of singles and couples (or two share mates). Hence the rate is not a whole number in this case as the average is set between one and two persons at 1.5.

The second occupancy rate is based on statistical values provided by the Gold Coast City Council (2013) and set out in tables in Appendix C. One table shows average values by statistical local area (suburb) for all dwellings. The second table shows average values by suburb for multiple unit dwellings, compiled for infrastructure planning purposes. Both tables need to be used with caution for the house and comparison apartment cases as noted below:

a. The house is in the Coomera locality that has an average household size of 3.0 per unit, which is much lower than the typical value of 4.0 per unit used for this study.

b. The 2-bedroom low rise apartment rate is the average 1.85 per unit for inner suburbs, which is the slightly less than the typical value of 2.0 per unit.

c. The 3-bedroom medium rise apartment comparable locality is Southport or Biggera Waters–Labrador at 1.6–1.7 per unit. A higher value of 2.1 per unit is used, which is the average value in an outer suburb, being more reasonable for a larger size unit and about the same as the typical value.

d. The 2-bedroom high rise apartment locality is Surfers Paradise, which has unusually low average occupancy rates of 0.8 per unit due to the tourist orientation. The nominated rate is the average value for the coastal strip at 1.3 per unit, which is lower than the typical value of 1.5 per unit—also averaged on the building configuration.

The graph in Figure 5.17 comparing embodied energy intensity indices conveys seemingly clear relationships between building types, but which actually disguise complex comparisons. The first (blue) series gives the impression that there is a very narrow spread in energy intensity per m^2 of GFA between all building types, ranging from 92.5 to 108.9 with a standard deviation of 6.7. This is an interesting result in itself that indicates all the commercial scale buildings have relatively similar building fabric, if all the internal unit fit outs are treated the same. However, variations of up to 18 per cent occur between the 6 storey building and both the other cases. The result is also unexpected in comparison with the single level house: it indicates considerable commonality with a building fabric comprising a concrete slab floor, brick veneer walls and concrete tile roof, and similar fit out. On the basis of these pilot cases, the type of building is not as significant as might be expected; although the gaps in the data for the apartment buildings must be kept in mind as they would increase embodied energy.

Yet the results highlight reservations expressed in the individual cases that the intensity per m^2 of GFA is a deceptive measure, because it does not take into account the numbers of bedrooms in each comparison dwelling, or the occupancy rates. The other series, focussing on these variables show a much greater variation above the base case. Interestingly the low rise and high rise building cases that compare 2-bedroom units with the 4-bedroom house are nearly three and two times respectively the energy intensity value per bedroom. This result is reinforced in the series comparing the typical and statistical occupants. The variability within each case is due to differences in typical and statistical occupancy rates. These are better indicated in Figure 5.16, but are disguised in Figure 5.17 in the reference indexing. This is because the house energy intensities are significantly different for each occupancy rate, but the index is not. The energy intensity of the low rise and high rise 2-bedroom units are similar using the nominated multiple unit dwelling rates, which is the expected result. The high rise unit is penalised by the lower occupancy.

The medium rise six storey building is about 23 per cent more energy intensive than the house, which corresponds to the larger 3-bedroom units. The increase takes into account the basement parking and the ground floor amenities and additional concrete. The consistency of the bedroom and typical occupancy energy indices is coincidental because the number of bedrooms equals the number of typical occupants, but significantly increases at the statistical value shown in Figure 5.16. Nevertheless, the initial analysis points to a tentative proposition that the six storey building is the preferred compromise for a more intense form of development offering house-size apartments, if only the building embodied energy is taken into account.

Because the initial analysis focuses on bedrooms and occupancy rates as the basis for comparison, there are three missing factors: the effect of larger living areas, the external areas, and the building footprint and shape. These three modifying factors are not evident in the graphical presentation:

- The living areas matter: each of the case B and case C apartments is larger than the house, partly because the living areas are larger. If some of this area were converted to another bed space, the apartments would be more energy efficient per bedroom and potential occupant. Alternatively the living area could be reduced.
- The external areas matter: the reference house has an external under-roof 17 m^2 verandah area, while the six storey building comparison apartment has 36 m^2 balconies that are twice that area. But the external area of the house could be the whole balance of the 570 m^2 lot area at no energy cost if uncovered. In contrast, the external area of any apartment above ground floor contains a significant energy cost of somewhat less than 14 GJ per m^2 of area.
- The building footprint and shape matters: the house is 185 m^2 area (including the garage). The 1540 m^2 footprint of the six storey apartment building is equivalent to 8 houses with garages, but less than 3 of the house lots. The 710 m^2 footprint of the 30 storey apartment tower is equivalent to nearly 4 houses and 1.25 house lots (although on a much larger site). The footprint and shape of these buildings determines the number of units per floor, the degree of connectedness and common areas, and the unit orientation. These architectural issues are briefly noted in section 2.4 of Appendix A and influence the embodied and operational energy of the building, but are not explained by the table or graphs of energy intensity.

5.6.2 Comparison of oil and gas related inputs

In searching for meaningful (practically significant) statistical measures, as highlighted by Graziano and Raulin (2007: 119), correlational statistics are determined to be of little value for all the above reasons. Differential research analysis on the single dependent variable of embodied energy per unit area GJ/m^2 (MFA flux as an energy index) is highly constrained, but needs caution in drawing conclusions on disparate cases (Graziano & Raulin 2007: 151). Although the energy intensity index is a theoretically relevant variable, the data gaps cause actual and potential input errors in all cases. The correlation measure is also problematic as it is only on four cases.

In any case, this index tells us only a little about the oil and gas inputs to the building construction, or about the degree of oil dependency. This is highlighted in the oil and gas inputs provided in Tables 5.5, 5.8 and 5.12 for bulk concrete and steel; and concrete, sand and gravel transport. These tables are summarised in **Table 5.14**.

Table 5.14: Comparison of oil and gas inputs to bulk materials (GJ)

Case items	Steel	Sand & gravel	**Concrete total**				Total energy	Structural energy %
	tonnes	m^3	25 MPA m^3	32 MPA m^3	40 MPA m^3	60 MPA m^3	GJ	% total building
Detached house (total structural embodied energy = 1,930 GJ)								
Quantities:	2.9	63.5	48.1					
Total energy GJ	11.4	6.7	24.5				42.6	
Waffle pods EPS						51.0	359.0	20.8
Case B: 3-4 storey units (total structural embodied energy = 31,560 GJ)								
Quantities:	203			1194.0	1196.0			
Total energy GJ	864	155.0		609.9	791.7		2,353.7	7.4
Case C: 6 storey units (total structural embodied energy = 95,376 GJ)								
Quantities:	432.3			2971.7	3327.4			
Total energy GJ	1697.7	449.0		1515.6	2206.1		5,868.4	6.1
Case D: 30 storey units (total structural embodied energy = 333,492 GJ)			Blockwork m^2		plus glass /steel frame walls 704 GJ			
Quantities:	1893.0		2200	8247.0	3448.0	576.0		
Total energy GJ	7433.8	734.0	1122	4206.0	2286.0	642.8	17,130.0	5.1

The proportion of total *structural* embodied energy attributable to oil and gas is indicated to be about 21 per cent of the house and a minimum of 5 per cent of the apartment buildings. The inference is that the case C average estimate represents 0.54 GJ/m^2, or only 3.8 per cent of a *total* embodied energy intensity of 14.25 GJ/m^2. This may suggest that from only an embodied energy perspective, the use of steel reinforced concrete in building construction is NOT problematic. However, in the case C medium rise apartment building it involves over 95,000 GJ of embodied energy. This conclusion ignores the greenhouse gas emission issue and should not be taken to exonerate Portland cement-based concrete as a sustainable building material.

5.6.3 Comparison of construction processes

Some obvious differences are noted in the case reports between constructing single storey domestic scale and multi-storey commercial scale buildings. The case A report photos in Appendix D illustrate the process for a single level house. The construction involves small quantities of materials delivered to individual sites for assembly and erection, mainly without mechanical assistance. Site organisation is minimal as the construction teams or sub-contractors follow a traditional process with low complexity. The typical ground floor slab becomes the on-site work space. The small scale generally means less on-site diesel powered plant and equipment. A single storey house requires minimal scaffolding in comparison with even a two-three storey building.

In contrast, commercial scale buildings are complex in relation to material quantities and the centralised site organisation and project management. The Appendix F report photos indicate the scale of concrete pouring, pumping equipment and size of cranes, the amount of ancillary scaffolding and protective screening required for the process. On-site organisation of materials and the labour force is more efficient and cost effective in the commercial scale projects, according to the construction manager of cases B and C. A high rise tower is the most complex of all building projects. Materials are delivered in bulk for the structural components: concrete and reinforcing steel for sub structure, columns, slab floors, and load-bearing walls; concrete blocks for walls, windows, doors and roofing. More elements can be prefabricated, such as pre-stressed beams, pre-formed steel reinforcing bars and mesh, and window walls, as well as unit fitout cabinetry. The building basement becomes a secure store and virtual construction factory. On-site processes are heavily dependent upon diesel powered plant and equipment, if not involving an existing serviced site for infill development.

5.6.4 Common transport and on-site energy issues

Transport of materials and labour is the largest direct oil-related input in all the cases of the study, based on current transport fuels. However the AGO study notes that ‘transport energy makes up a relatively small percentage of overall energy inputs, even for transport over long distances (AGO 2006: 6). In contrast, the on-site energy is a different story, depending on the site location.

Transport and workforce issues

All cases are completely dependent on road transport for materials, components and labour. Hence the deceptively small recorded transport embodied energy in each case is not the whole story in examining the possible oil related impacts in a future oil constrained scenario. While it is possible for a builder to schedule material delivery simultaneously to multiple sites for detached houses in greenfield estates, that is only feasible when houses are constructed on a coordinated project basis—e.g. where house and land packages are offered to the market in small stage releases, or several houses are investor owned for the rental market. The key point is that all the road transport relies on diesel, petrol or LPG powered vehicles, and hence on the oil economy. The vulnerability of fuel availability and the use of alternative fuels in housing construction practices and labour transportation is an important factor. In the future the choice of fuel options will widen as compressed/liquefied natural gas and even compressed air-hybrid powered engines add to the existing fuel choices. Outer urban greenfield locations are more remote from public transport and the goods supply network.

Commercial scale buildings rely on more centralised and efficient organisation of the supply chain than detached housing and effectively represent many dwellings built in one place simultaneously. The road haulage of materials and goods is an important aspect of the construction that is difficult to quantify accurately, partly because of the diverse sources of material supply and the goods distribution networks from Brisbane and elsewhere to the Gold Coast. For example, section 5.4.2 notes that each flooring pour for the six storey building relies on several batching plants all over the Gold Coast to supply 65-75 mixer loads of product to maintain continuity of the process. Basic materials are sourced from Brisbane as well as local suppliers and apart from sand and gravel; all materials apart from sand and gravel are imported into the region.

While tradespeople may try to live close to work, the geographic variety of sites and the shifting temporal nature of the suburban housing market make it difficult to achieve such a desirable aim under present lifestyle circumstances. On a commercial scale project, the labour force may bring individual tools to the job, but unlike house building, the larger tools and construction equipment are normally stored on-site. This could allow workers to travel by public transport, but only if convenient and available for early starting times. Public transport would be most viable in urban in-fill projects.

On-site power issues

On domestic scale housing project sites, the power requirements are met by small generators in greenfield sites and by a single phase domestic electricity connection in powered or infill sites. The case A data indicates that direct energy consumption for construction of the detached house is of the order of 350 kWh of electricity at peak rates, which is taken from local mains power. This is a small amount and only about half of a typical three months' supply of domestic electricity.

On commercial scale sites, diesel generators provide power until 3-phase permanent mains power is connected for the cranes, hoists and lifts, and single phase power for general electrical needs and lighting. The advantage of an infill site development is that the power is available from commencement, and the case D project did not experience the delays of the greenfield cases. Direct diesel powered plant and equipment include dewatering pumps, concrete pumps and helicopter vibrators used on the concrete floors. The energy for these items is omitted due to lack of operating data. The power used in battery operated hand tools is also excluded from the calculations, because most would be charged off-site overnight. In any case the mains-generated electricity has only minor gas input in the mainly coal-fired power system.

Building lifts energy

The embodied energy in the building lift systems is considered to be only a small missing factor, as the lifetime operating energy far outweighs the embodied energy. Two estimates are that one lift consumes 5-15 per cent of the total *operating energy* of a residential building (Building Codes Queensland 2010: 13; Roaf 2010: 35). The aim may be to minimise the need for lifts to reduce operational energy use, but they are a requirement in most residential buildings over two storeys in the Australian context, as noted in Chapter 4, section 4.2.4. Two or more lifts are required in buildings over 10 storeys, and the high rise tower has three high speed lifts serving all levels.

An energy consumption estimate was made for this research of a 30 year old seven level building comprising 10 apartments with identical floor plans. The assessment analysed the electricity records for two of the 2-bedroom apartments, compared with the lift and common area lighting consumption. The results summarised in **Table 5.15** reveal the single lift consume approximately 14-18 per cent of estimated operating energy of the whole building. This result serves to strengthen the conclusion that lift operating energy is a significant factor, inherent in all the apartment building cases.

Table 5.15: Energy consumption for a single lift in a seven storey building

10 unit apartment building:		Total days	Approx. Total kWh	Average daily kWh	Average $ per kWh
3 month average for 2 units:		88.5	832.3	9.40	0.2005
3 month total for 10 units:		88.5	8,322.50	94.04	0.2005
Total per year for 10 units:			**34,324.44**	**94.04**	
Common area (CA) lift and lighting:					
Average per year:		365	**8,861.13**	**24.28**	0.2005
Total for building per year kWh:			**43,185.56**	**118.32**	
Lift only p.a. allowing 10% for lights:			7,975.01	21.85	
Lift only p.a. allowing 30% for lights:			6,202.79	17.00	
LIFT % kWh at:	90% of CA average		**18.47%**	**18.47%**	
	70% of CA average		**14.37%**	**14.37%**	

5.6.5 Cross-case conclusions

This section addresses four essential specific questions set out in the protocol to be asked across the multiple cases:

A. Are the cases comparable in terms of consistent, valid data?
B. Do the cases show sufficient diversity to be treated as separate representative examples in the residential typology?
C. Is a further case required to show the range of diversity across the typology?
D. Is a refinement of the analysis needed to draw out the conclusions?

A. Is data consistent and valid for comparison purposes?

All the cases provide adequate descriptive and quantifiable data for comparative purposes, and of a consistent standard. Some of the gaps are common to all cases, such as HVAC, plumbing and electrical services information. Other gaps are specific to the apartments as a sub-group, such as the unit fitout of equipment and fittings. A factor based on the house fitout is added to compensate for the gap and to improve consistency of embodied energy across the cases. Gray (2009: 155) cautions that 'to ensure validity, a research instrument must measure what it was intended to measure'. The key measure in this pilot study is embodied energy intensity, as a quantifiable index that can be compared across all the cases. This has been achieved and is considered to provide valid results.

B. Are cases representative of the residential typology?

The careful selection of the cases in accordance with the case study design criteria in Section 2.3 of Appendix A has ensured that the buildings are representative examples of the residential typology. The question of sufficient diversity between cases is relevant to the low rise four storey and medium rise six storey apartment buildings. Both are similar in construction processes, partly because they are by the same developer and builder. The four storey building could be classified as a medium rise building, because of the enclosed ground level car parking. However, it is similar to other three storey apartment buildings above unenclosed parking and has been classed as a low rise building for the purpose of this study. It contrasts with the six storey building that has a basement level. Cases B and C therefore allow a comparison between buildings with ground level parking and a basement. The case D tower satisfies all high rise types.

C. Are further cases required?

It is not considered that further conventional case buildings are required. A two storey terrace-house building near the case A house was partially analysed to test the results. It was not included in this assessment because it was not sufficiently different from the single storey house in materials or construction processes (apart from scaffolding). The data is available for analysis as future research. Low rise apartments above a commercial ground floor are an alternate form that was also investigated, but case B is sufficient to represent that type, with the ground floor flexibility for parking or use. Unconventional and alternative materials are considered in cases A and B. However, the domestic scale residential market at the Gold Coast is overwhelmingly conservative in use of materials, favouring clay and concrete brick veneer with tile or metal roofs. The commercial scale market is dominated by poured and blockwork form concrete structures, such that alternatives are not worthwhile pursuing in cases C and D.

D. Is refinement of the analysis necessary?

Building modifications and sensitivity tests have refined the analysis of individual cases and cross-case comparisons, and are considered suitable to draw conclusions.

5.7 Case study conclusions

This chapter has addressed research question 2.2 to analyse the development and construction factors for a representative range of residential building typology to indicate the relative vulnerability to future oil supply constraints. The analysis suggests that all residential buildings are vulnerable both on an embodied energy basis and on the underlying reliance on oil powered transport. This concluding section makes suggestions for further research to improve the method and refine the recorded data results; and finally draws study-wide inferences on the key development aspects. It firstly answers the five essential specific questions set out in the protocol to be asked of the entire study:

A. Is the study sufficiently complete for the purposes of assessing the proposition?
B. Is additional data required to interpret the results in the study evaluation?
C. Are the conclusions drawn from the study valid and practically significant?
D. Are the limitations of the study so serious as to affect the research method?

5.7.1 Case study questions

A. Is the study sufficiently complete?

The study has analysed four cases representative of the urban transect in detail and derived both qualitative data and a quantitative energy intensity index, with which to assess support for the Part 1 proposition on the significance of oil dependency in development.

B. Is additional data required?

No additional data is available at the completion of the thesis research period. The expected Australian life cycle inventory data is yet to be published. When this becomes available, the material flow inputs can be re-analysed to check the results against the database. The lack of availability has not affected the internal comparison, because the same material embodied energy factors have been used consistently in each case.

C. Are conclusions valid and practically significant?

The external validity is important to be able to generalise the results of this study to a wider setting (Graziano and Raulin 2007: 182; Gray 2009: 156). The study uses multiple case replications by extending the analysis to four cases to increase the validity. Each case is considered to be representative of the residential typology. However, because of the single case in each category, probabilistic measurement is ruled out and the causal propositions are deterministic—the if ‘x’ then ‘y’ argument (Gray 2009: 262). The empirical nature of the analysis means that the study can be replicated by other researchers, and in fact the case A house is referenced to a similar Melbourne study (Crawford 2011). The reliability is increased by developing a protocol as suggested by Yin (2009: 79). It is concluded that the energy intensity approach is a valid measurement and the study can be replicated to have external greater validity.

D. ***Does the study have serious limitations?***

This is a pilot case study and therefore the results are regarded as preliminary indicators of the embodied energy in typical residential buildings at the Gold Coast. All the cases underestimate the actual embodied energy in similar ways. Hence the data collection errors are reasonably consistent across all the cases and do not invalidate the comparisons. The data could be improved by the recommended further research.

5.7.2 Further research suggestions

The following suggestions are made for further case study research to improve the method and refine the recorded data results:

a. The embodied energy factors (energy per unit) were checked against the BPIC-LCI database (BPIC 2012) as the only Australian source for MFA. In practice, the MFA analysis showed this has serious flaws. The long awaited ALCAS AusLCI is the preferred source and when it is published, should be used to check the calculations in a triangulation with the Crawford (2011) sources.

b. Greater accuracy in embodied energy and oil inputs would be gained by calculating the plumbing uPVC, HDPE, polybutylene piping; and PVC electrical cable sheathing used in the building. The quantities of such petrochemicals are not as important as the dependence on the oil and gas inputs to make them.

c. The detailed embodied estimate CDROM spreadsheets note significant gaps in the data that make the overall calculations highly conservative, because of unknown energy intensity or difficulty in allocating energy. Land development inputs would increase greenfield site energy. An allowance is made for the hydraulic (HS), mechanical (MS) and lift services in the spreadsheet calculations, pending further research. These elements differentiate the six and 30 storey building types from a low rise type. Lift services are relevant to operating energy.

d. The material and workforce transport are common elements and suffer from similar exclusions in all the pilot case studies. This is a shortcoming of all cases that the author made efforts to rectify. Further research is warranted to improve the assessment of these elements in relation to various buildings and locations.

5.7.3 Study-wide inferences

The use of material flow analysis as a basis for empirical case study investigation of the petroleum-related inputs to residential development and construction has yielded interesting and valid results. The principal measure is the embodied energy intensity expressed as the energy per unit area (GJ per m^2) across all the cases. The analysed six storey building has least embodied energy intensity. The embodied energy is also compared on a more relevant per-bedroom and per-occupant basis. The results show that the detached house has least embodied energy on both these measures. The six storey apartment building is the next most efficient case with about 65 per cent more embodied energy than the house on an indexed comparison. However, the general underutilisation of detached housing could be improved if the design permitted flexible tenancy and multi-generational sharing. The analysed six storey 3-bedroom apartments are in fact larger than the 4-bedroom house and would provide suitable family accommodation for two adults and two children. The 2-bedroom apartments are least efficient, particularly on the basis of typical and statistical occupancy factors.

The somewhat surprising tentative result is that the oil and gas proportion of total structural embodied energy is 21 per cent of the house, but only an average 6 per cent of the apartment buildings. The inference is that the average apartment estimate (case C) is 0.54 GJ/m^2, or only 3.8 per cent of a *total* embodied energy intensity of 14.25 GJ/m^2. This inference could suggest that from only an embodied energy perspective, the use of steel reinforced concrete in building construction is *not* problematic. This conclusion, however, ignores the greenhouse gas emissions and because of its volume in use, should not be taken to exonerate concrete as a sustainable building material.

The graph in Figure 5.17 comparing embodied energy intensity indices conveys seemingly clear relationships between building types, but actually disguises complex comparisons. The first (blue) series suggests there is a narrow spread in energy intensity per m^2 of GFA between all building types, ranging from 92.5 to 108.9 with a standard deviation of 6.7. This result indicates that all the commercial scale buildings have relatively similar building fabric, if all the internal unit fit outs are treated the same. However, variations of up to 18 per cent occur between the 6 storey building and both the other cases. The result is also unexpected in comparison with the single level house: it indicates that the commercial scale buildings having a relatively similar building fabric are not significantly different to the brick veneer detached single storey 4-bedroom house with a similar fit out. This may be because of the economies of design where dwellings have vertical and horizontal attachment. On the basis of these pilot cases, the building construction is not as significant as the type—form, height and density. The gaps in the data for the apartment buildings—e.g. for HVAC and plumbing—must be kept in mind as they vary the total building embodied energy.

Transport of materials and labour is the largest direct oil-related input in all the cases of the study, based on current transport fuels This finding is contrary to a study that suggested transport energy is a minor component (AGO 2006). All the road transport currently relies on diesel, petrol or LPG powered vehicles, and hence on the oil economy. The deceptively small recorded transport embodied energy in each case is therefore not the whole story in examining the possible oil related impacts in a future oil constrained scenario. In the future the choice of fuel options will widen for small vehicles as compressed/liquefied natural gas and air hybrid powered engines add to existing petrol, diesel and LPG fuels. However, heavy vehicle fuel choices are limited.

This chapter completes the Part 2 research and adds empirical evidence to the documentary research of chapters 3 and 4. The findings support the proposition that oil-related inputs are significant in building construction and inform Part 3 research.

Part 3

Towards the oil-constrained sustainable city

Part 3 of this research involves a grounded theory (GT) investigative approach using an abductive analysis method in accordance with section 3.1 of Appendix A. This method investigates the phenomenon (**P1**) of global petroleum (oil) supply depletion as an emerging global wicked problem in relation to the phenomenon (**P2**) of sustainable forms of cities. Chapters 6 and 7 address research question 3 to develop grounded theories about sustainable residential development in an oil-constrained future within the Australian urban context as the desirable outcome (**P3**). The methods develop the systematically generated GT explanatory hypotheses in Chapter 6 into grounded theories in Chapter 7. The grounded theories form a refined integrated conceptual framework, which is applied to the City of Gold Coast in Chapter 8. The refined integrated conceptual framework that can be expressed abstractly as:

P1 global oil supply depletion affects P2 sustainable forms of cities ⟶ P3 desirable outcome

The analysis draws on the urban residential forms, mobility and other relevant sustainable values of pre-oil economy cities and the experience of nominated modern cities. The Chapter 7 analysis derives and verifies grounded theories and models through a focussed interview method. The refined integrated conceptual framework and the adjusted planning system are then applied in Chapter 8 to the identified case study City of Gold Coast. Current planning models of sustainable development are overviewed for relevance in an oil-constrained city. A scenario method is utilised to illustrate possible adaptive and maladaptive planning outcomes in the transitional and oil-constrained futures. The chapter demonstrates how land use planning can assist in the transformation towards oil-constrained sustainable urban residential forms in the Gold Coast and wider context. **Figure D** summarises the research design for Part 3.

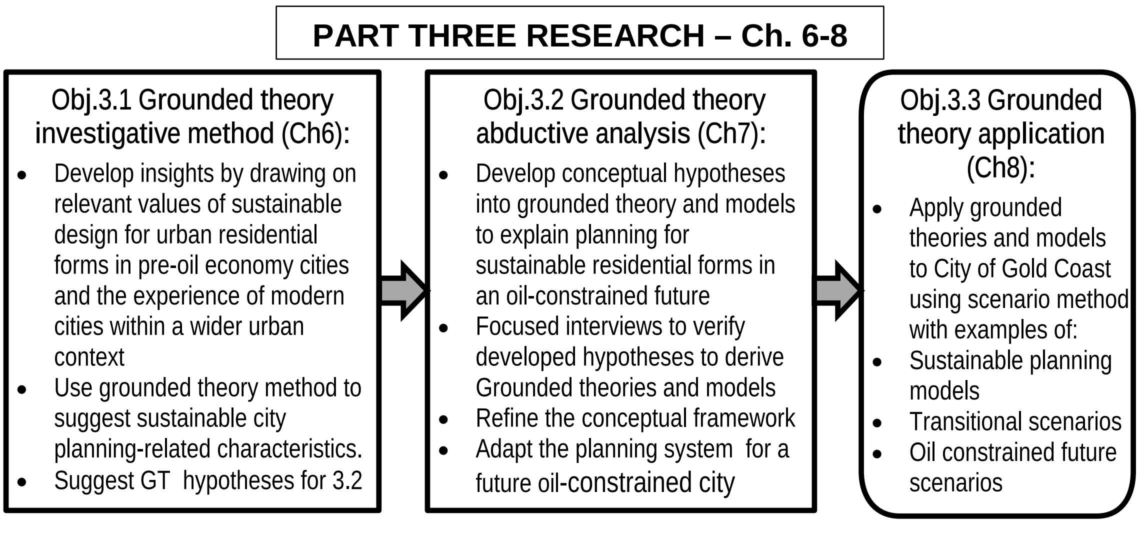


Figure D: Part 3 research design summary map

Chapter 6

In search of the sustainable city

> *Energy is the key to economic development, and renewable energy is the key to a future without dangerous climate change.* (United Nations 2009b)

The aim of this chapter is to link the data on oil depletion impacts in Chapter 3 and the case study examples in Chapter 5 to the transformation of urban residential forms towards an oil-constrained future. A grounded theory (GT) investigative approach uses an abductive analysis method in accordance with section 3 of Appendix A. The reasoning for using this method to address Objective 3.1 is in part due to the nature of oil depletion as a global wicked problem that is being manifested as a corollary of the global financial crisis (the great recession). It is also a problem being viewed from the plateau of peak oil production without historical precedent, except for the 1973 oil crisis. In the abductive method, 'the goal is to explore the data, find a pattern, and suggest a plausible hypothesis' (Yu 1994). The analysis draws on the design of urban residential forms, mobility and other relevant sustainable values of pre-oil economy cities and the experience of modern cities. The observations assist in the search for the qualities of sustainable cities by 'making comparisons as tools to assist in moving from the level of description to abstraction in understanding the data' (Strauss & Corbin 1998: 85).

The following sections document the coding and categorisation of the data. The classic GT analytical process moves from open coding of the data to axial coding of the data category relationships; and selective coding to theorise hypotheses (as adapted in Appendix A). While the open coding of the observation memos, photos and video are subjective, they are complemented in the axial coding by interviews with local strategic planners or similar professionals, and supplemented by access to published online or printed data. Thus the data comes from multiple sources, which is a feature of GT methods. Only a selection of the observation memos and data records are referred to in the body of the thesis, sufficient to illustrate relevant sustainability features with examples from the cities visited. More photo and video data are recorded in the CDROM. The core- and sub- categories of revealed patterns are used to make grounded theory hypotheses about sustainable cities in an oil-constrained future for verification in Chapter 7.

6.1 Qualities of pre-oil economy cities

Cities historically have undergone transformative shifts in changing technological, economic and political circumstances (including major wars). Many old cities are valued as being sustainable and resilient (Gehl 2010). The discussion about terminology in Chapter 2 distinguishes between these terms; however 'sustainable' is used in this section, because the planning literature favours this term and 'resilient' is used more in the disaster management context. During the course of this research, many old cities were visited, as well as modern ones, in Europe, North America, Asia and Africa, to discover at firsthand their relevance to cities undergoing the transformative paradigm shift toward the post-oil environment. Several cities and towns visited in those countries are promoted as having 'sustainable' features. Other cities visited are regarded as being unsustainable, yet they also provide useful lessons for the future. This section records the open coding of the observations of pre-oil economy cities.

Part of the value in visiting a wide range of old and new cities was to minimise the so-called 'hindsight bias' illusion, in which 'the past always appears more certain than it was, and makes the future feel more uncertain' (Gardner 2009: 358). In the case of this study, it is important not to suffer the illusion that the inputs to, and outcomes of past urban form, were better than the present and possible future urban forms. Reference is made to this in section 6.1.1 in relation to the 1800s period of urban development.

6.1.1 Observations of pre-oil economy cities

In his seminal book *Good City Form*, Lynch (1984) proposes formal qualities of the 'good city': it is vital, sensible, well fitted, accessible, well controlled, and all achieved with justice and internal efficiency. More generally it is 'a continuous, well connected, open place, conducive to development' (Lynch 1984: 235). Lynch explains these qualities as having characteristics that make it safe, structured and legible; having a form that is adaptable; having accessibility that is diverse and equitable; and having control systems that are responsive and appropriate to the circumstances (Lynch 1984: 235). He illustrates his ideas on urban design with examples from well-known cities and with many graphics to catalogue ideas that have and can be implemented.

Lynch references many ideas to the European cities of the pre-oil economy through his research based in Italy including Florence, Barcelona in Spain and Paris. These design principles from the 1980s form substantive theory for the GT analysis, which are still relevant today, even in the age of digital technology in the post-industrial knowledge city. The photos in **Figures 6.1a – c** illustrate typical streetscapes in the central areas of just some European cities visited, including Aachen, Amsterdam, Bonn, Freiburg im Breisgau (Germany), Heidelberg, Munich, Orléans, Paris, Seville, Vienna and Zurich. A selection preference was for cities with centres intact from World War 2 bombing. **Table 6.1** gives contextual details—dimensions and properties—of some of the cities visited, for coding of features that appear relevant to this research analysis.

In order to have relevance to the Gold Coast, the nominated cities are all connected to water, as are semi-coastal Amsterdam and 11 river oriented cities. The city populations are in a wide range from 108,000 to 2.2 million, compared with a Gold Coast 2011 census population of 494,500 (ABS 2012). Paris is by far the largest city, but is included because of the regulated design of residential apartment buildings. In most cases the old central areas have a dense urban form as indicated in **Figures 6.2a - b**. The selected 'sustainable' features of the cities, indicated photographically in Figure 6.1, are framed by enduring qualities of urban design noted by Lynch (1984) and others cited in section 2.1—e.g. Jenks et al. (1999), Carmona (2010), Osmond (2010), Kropf (2011)—and below.

To a first time visitor, walking or relying on public transport, the initial observations of each city provide valuable contextual insights into the feel of mainly the central area and 'old city'. The old cities (altstadt in German) exhibit the charm of streetscape and plazas captured by Camillo Sitte in his urban design studies (as depicted in Collins, Collins & Sitte 2006) and expounded by architects including Rob Krier (1979), Lynch (1984) and Gehl (2010). These central areas were essentially developed historically and constructed in the pre-oil economy—i.e. pre 1900. Hence a particular focus in selecting these cities is on the urban fabric developed in the nineteenth century, prior to introduction of oil in all aspects of city building, industry and transportation. Similar historic places survive in Australian cities, including central Melbourne, The Rocks in Sydney, Newcastle and small parts of the central areas in Adelaide, Brisbane, Hobart and Launceston. Prior to the 1900s, the selected case study city of Gold Coast was a string of small coastal villages, without a strong central urban area (Prideaux 2004: 40).

Whatever was built in the 1800s period could logically continue to be built with all the advantages of electricity, the technological inventions of electric lifts (elevators) and self-lifting cranes, and significant advances in materials science. However, these materials include petrochemicals such as plastics (e.g. PVC and foam insulation), which could become problematic unless non-petroleum substitutes are developed and scaled up to meet global demand. Hence it was important to keep these factors in mind while observing sustainable and adaptable features in the urban morphology of pre-oil economy cities that might be relevant to a transformed city in the oil-constrained future. Of course, these cities have evolved in the use of renewable energy, modern technology and transport, so they provide models of more or less successful transition to the future. Several of the cities visited are involved in European sustainable city and smart city movements including the European Sustainable Cities Movement (2013), Reference Framework for Sustainable Cities (2013), SmartCities initiative (European Commission 2013) and more broadly the ICLEI-Local Governments for Sustainability (2013).

In several cities a photographic or video record (included in the CDROM) was made of a typical urban transect, along a tram or bus route. The urban transects in such cities—and also in post-war construction and more modern cities developed in the twentieth century—were evidently more complex than the neat diagram of Figure 2.4. It was apparent that the old-city authorities preserved or adapted historical buildings, developed new buildings and precincts, and maintained or introduced mixed uses into the urban fabric. Multi-storey apartment buildings of 5-7 storeys were evident in all the old cities (Figure 6.1) and even in middle-outer urban areas along public transport routes. Table 6.1 indicates the density of the old cities is 3,555-5,000 persons per km^2 (35-50 per ha), although the images in Figure 6.2 would suggest greater density. The significance of this urban residential form is its relevance to the findings of the case studies B and C in Chapter 5, even though the construction materials and methods are more advanced. The transect photos in the CDROM also highlight the value of fixed track transport as a place making catalyst (Barton 2000, Riddell 2004, Register 2006).

Münsterplatz, Aachen town centre, Germany showing shop top living, outdoor eating, bikes and scooters

Amsterdam typical canal 5-6 storey development

Bonn Markt Platz with 4-5 storeys of shop top living

Mix of old and new Paris from Montparnasse Tower to narrow Rue D'Odessa (centre) and wide Blvd du Montparnasse (left), showing 6-8 storey apartments in perimeter blocks with light wells and landscaped courtyards. Modern buildings in the foreground and left side have green roofs.

Paris elevated Metro line 6. View along Rue de Rennes to Montparnasse Tower. Green wall on Quai Branly. Photos show parts of the 1800s Hausmannian monumental axes of wide boulevards

Figure 6.1a: Photo montage of streetscapes in old city areas of Europe

Source: Photos by the author July 2013

Quiet street and steep apartment street in Montmartre area of Paris. Pedestrian street with trams Orléans, France

Mix of old and new in Heidelberg, Germany; Altstadt shared shopping street; Bicycle parking at main rail station

Vienna Ringstrasse redevelopment Ringstrasse apartment complexes Hafnersteig Platz in old Vienna

Freiburg altstadt shared street with trams Munich Petuelring area 5-6 storey apartments Zurich courtyard

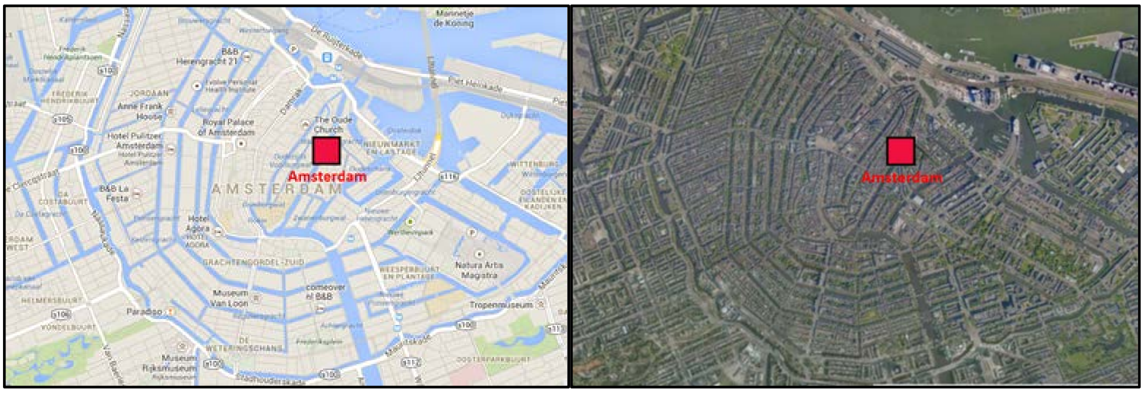
Zurich central area: historical buildings along the Limmatquai. Seville Spain: typical courtyard in central area

Figure 6.1b: Photo montage of streetscapes in old city areas of Europe

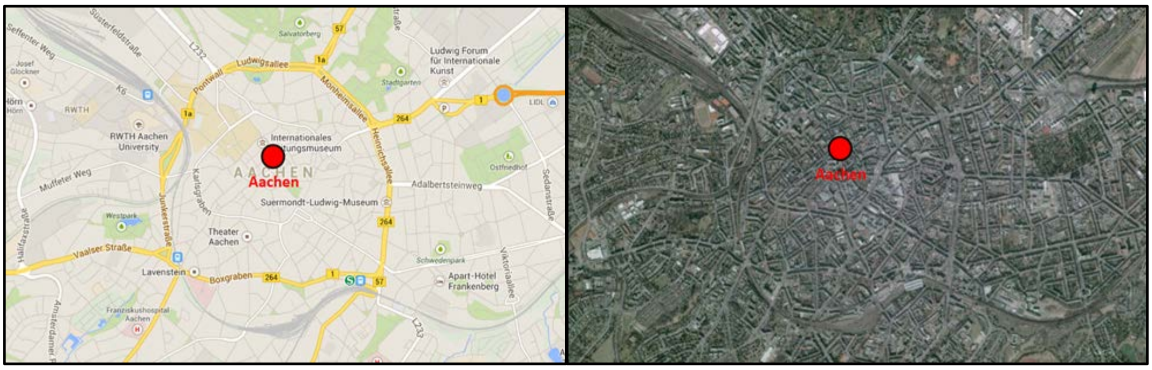
Source: Photos by the author July 2013

Figure 6.1c: Photo montage of streetscapes in old city areas of Europe -
Amsterdam: Korte Leidsedwarsstraat and Leidseplein square late evening activity

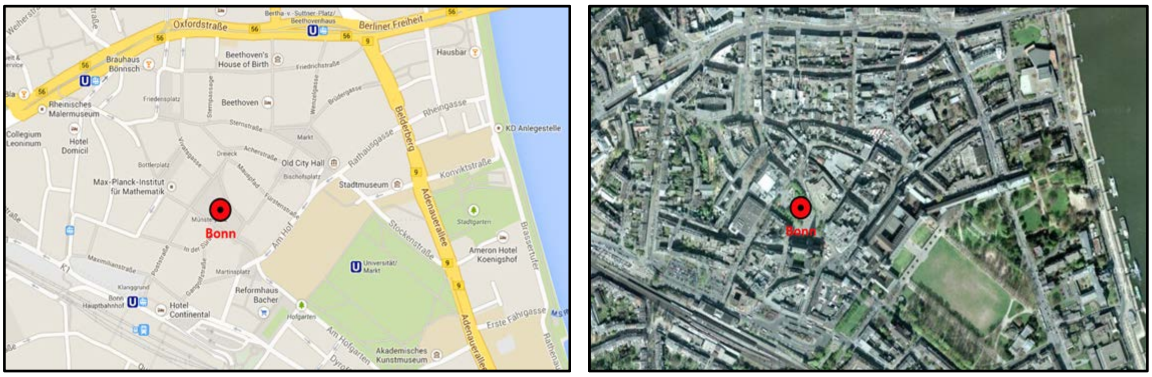
Source: Photos by the author July 2013



Central Amsterdam area in map and satellite imagery



Central Aachen area in map and satellite imagery

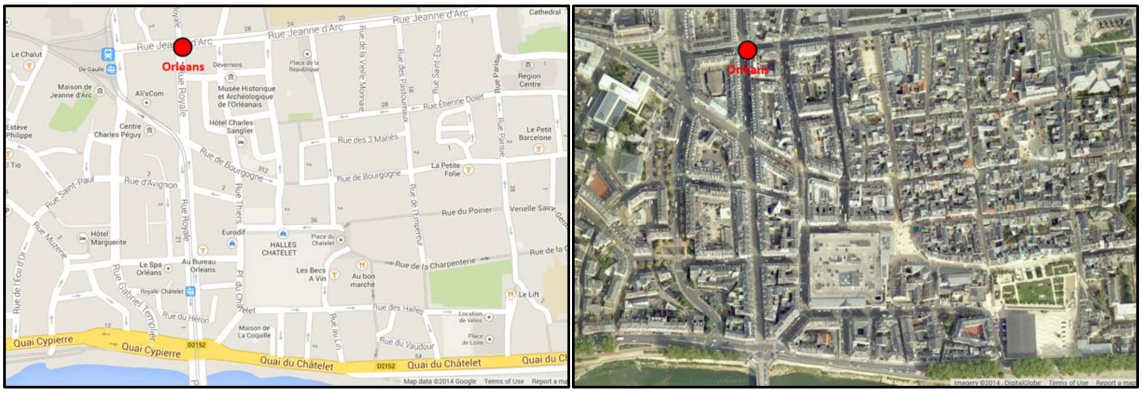


Central Bonn area in map and satellite imagery

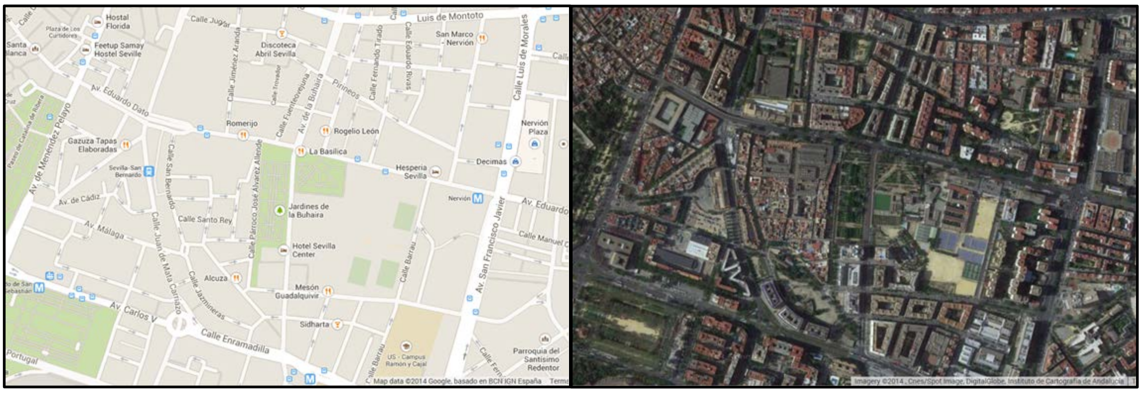
Figure 6.2a: Reference cities central ‘old’ area urban forms

Source: Google Earth; Maps 2013

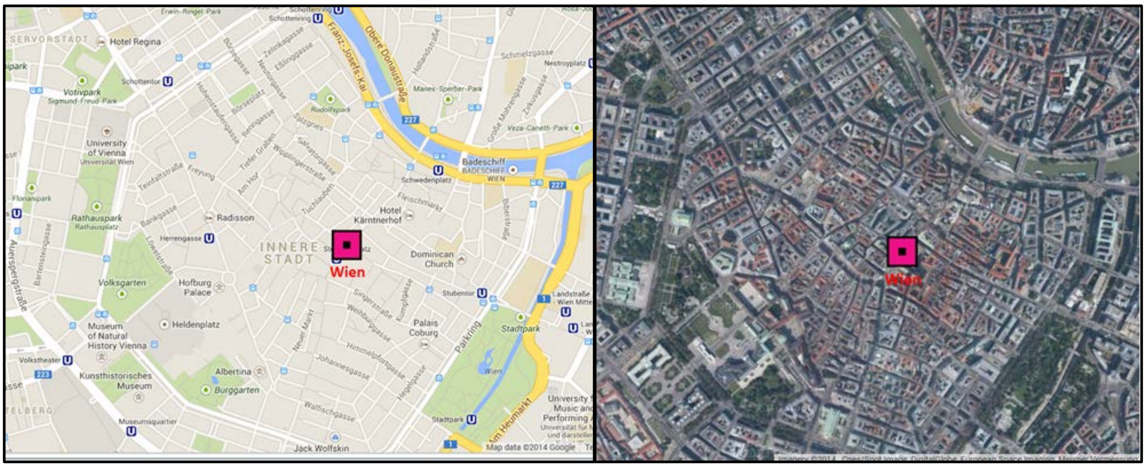
Central Florence (Firenze) area in map and satellite imagery



Central Orleans area in map and satellite imagery



Central Seville (Sevilla) area in map and satellite imagery



Central Vienna (Wien) area in map and satellite imagery

Figure 6.2b: Reference cities central 'old' area urban forms

Source: Google Earth; Maps 2013

Table 6.1: Contextual details of cities included in thesis analysis

Country	Cities	Dimensions	Sustainable development properties		
		Population area, density	Focus of city features	Transport features	New energy features
Austria	Vienna/ Wien	City: 1,681,000 Metro: 2,269,000 Altstadt: 16,375 Inner pop.: ~486,000 Area: 415 km^2 Central area density: Altstadt: 5,650/km^2	1800s period of interest – the Ringstrasse redevelopment. Multi-centric Smart city –	Tram, bus, electric bus Bike sharing	Hydro power Solar and wind power. (4 Vienna Citizens' Solar Power Plants). Forest-

		Inner precincts: 13,000-22,000/km^2	Urban Transform project		biomass power plant
France	Paris	~2,113,000 in 105 km^2 central city area. Metro: 11,679,000 Central area density: 21,300/km^2 (213/ha). In 1999, the11th arrondissement eastern quarter had densities close to 100,000/km^2 (1000/ha)	1800s within central 20 districts called *arrondissements*. Paris is the most densely populated city of >1,000,000 in the Western world. (Insee data 2013)	Metro Light rail Bus Bike sharing *Velib*	Solar and wind power
France	Orléans	City: 114,000 Area: 27.5km^2 Central area density: 4,155/km^2	Regional city 1800s period	Tram only	Solar and wind power
Germany	Aachen	City: 241,300 Metro: 1,240,000 City area:161km^2 Metro area: 628.9 km^2 City area density: 1492/km^2	1800s period	Bus only	Solar and wind power
Germany	Bonn	City: 307,500 Area: 141 km^2 City area density: 2,196/km^2	1800s period	Tram, U-Bahn Bus	European Gold Energy Award 2011
Germany	Heidelberg	City: 150,350 Area: 109 km^2 City area density: 1,381/km^2	PassivHaus Bahnstadt	Tram, bus	Solar and wind power
Germany	Freiburg im Breisgau	City: 220,000 Area: 153km2 City area density: 1,425/ km^2	New smart city overlaying old	Tram, bus	Solar and wind power
Germany	Munich/ München	City: 1,367,000 Metro: 2,600,000 Area:310km^2/1929 km^2 Central area density: 4,468/km^2	1800s and new PassivHaus development	Tram, bus U-Bahn (metro)	Solar and wind power
Italy	Florence/ Firenze	City: 375,000 Area: 102 km^2 Central area density: 3,574/km^2	Agenda 21, 1800s period	1 Tram line, bus	
Netherlands	Amsterdam	City: 762,000 Metro: 1,536,000 City Area: 166 km^2 Central area density: 4,822/ km^2	1800s period. Public & active transport. New 'UrbanTransform' project.	Tram, bus Bike sharing and culture.	Solar and wind power
Spain	Seville/ Sevilla	City: 700,000 Metro: 1,135,000 City area: 141 km^2 Metro area: 702 km^2 Central area density: 4,955/km^2	1800s period, southern city in Mediterranean hot climate	1 Tram, bus 1 metro line Bike sharing	Concentrating solar thermal (CST) power; Wind power
Switzerland	Zurich	City: 380,800 Metro: 965,000 City area: 88 km^2 Metro area: 935 km^2 Central area density: 4,329/km^2	1800s period, public transport	Tram, bus, trolley bus	Hydro power

Source for population statistics: City Mayors Foundation (2013a, 2013b) – data is mainly for 2011-12
City density Source: www.citypopulation.de/Europe.html

NOTE: To convert population densities to persons per ha, divide by 100 – e.g. 5,000/km^2 = 50/ha.

6.1.2 Categorisation of open coding

The open coding resulting from the European pre-oil economy city observations is categorised in **Tables 6.1** and **6.2**, firstly for the contextual details; and secondly for the grouping of concepts and their properties to show themes and relationships. These may lead to theorising about the core variable or category. These terms are somewhat interchangeable; however Glaser's 'core variable' (2004: 9) is more oriented to objectivist thinking leading to deductive analysis of the subsequent derived propositions. The structure of the coding categorisation is arranged as follows (rank 1 is highest):

Data (from multiple sources) → **Concepts** → **Grouping** → **Group relationships** → **Rank**

Table 6.2 summarises the theoretical sampling of data (text and visual properties) and allocates them to concepts, which are abstracted as labelled phenomena for the purpose of grouping into themes relevant to the general urban and environmental planning domain. The theoretical purpose of the groups is to explicate relationships developed from the open coding according to the criteria of relevance to sustainable development. These relationships also draw upon and relate to archival and empirical analysis in Chapters 2–5 as a means of comparing and validating the grouping selections.

Finally the **groups are ranked** according to an ordinal scale of importance based on relative dependencies between groups—i.e. the scale has no interval or ratio dimensions. The ranking is made to compare three future scenarios for these cities, which are explained after the table (note some groups are equally ranked):

A. contemporary urban development based on the historical precedence of the selected sample of pre-oil economy cities, smart city and climate change policies;
B. continued urban development under conditions of unconstrained petroleum supply, with smart city policies; coupled with unmitigated accelerating climate change; and
C. modified urban development under conditions of constrained petroleum supply, with smart city policies; coupled with mitigated climate change.

Table 6.2: Categorisation of open coding

Data summary	Concepts	Group	Relationships	Rank*
Politico-economic functions of the city in its region & country	Urban hierarchy scale and city size	Socio-economic hierarchy (SEH)	SEH influences the UMor & investment	2/2/1
Historical development of city: focal centre or multi-centric	Urban transects – simple or complex	Urban morphology end result (UMor)	UMor integrates USUs, UDes, UMet	2/2/2
Street pattern: grid, concentric, monumental, haphazard, alleys	Urban form spatial structures/patterns	Urban structural unit (USU) framework	USUs relate to UDes, UMet within UMor and influence Mob-trans & Energy-flows	1/1/1
Streets, plazas, parks: places to move through & socialise in	Urban public realm, social interaction	Urban structural unit (USU) framework		
Block size: short < 100m, long > 200m, building continuity	Built environment and street interface	Urban fabric and design (UDes)	UDes influences and develops USUs and	1/1/1

Walkable streets, direction finding, focal and end points	Mobility and legibility of spatial structure	Urban fabric and design (UDes)	relates to Mob-trans by integrating public transport and the pedestrian network. UDes also influences Energy-flows in the efficient siting and design of buildings	
Building types: commercial, residential, public, churches, monumental, landmarks	Urban fabric typology for mixed uses and apartment living	Urban fabric and design (UDes)		
Building heights: low 1-3 storeys, medium 4-8 storeys, high > 8 storeys	Urban fabric scales: dense inner urban development	Urban fabric and design (UDes)		
Building materials and sources, road/plaza sealing and paving surface materials	Building/construction technology, resource conservation	Urban metabolism (UMet): building flows and stocks	UMet relates to USUs and UMor as the variables in UDes, Mob-trans and Energy-flows that determine the urban flows and stocks	3/3/2
Energy efficiency in buildings: - Embodied energy - operational energy - Heating and cooling methods	Building energy technology and conservation	Urban metabolism (UMet): building related energy flows		3/3/2
Transport evolution: pre-oil, traffic free areas, electric trams, traffic management, private car or public transport dominant	Transport technology and public-private investment policies	Mobility and transport system factors (Mob-trans)	Mob-trans relates to UDes and influences USUs; and critically depends on Energy-flows. Types of public transport are determined by the urban public policies & investments. Mob-trans is also inter-urban & international	3/3/3
Public transport types: trams, light rail underground, heavy rail, electric trolley buses, fossil fuel powered buses	Transport systems and networks and public investment policies	Mobility and transport system factors (Mob-trans)		3/3/3
Traffic hierarchy: prime vehicle access, shared pedestrian-vehicular traffic, pedestrian	Movement & mobility hierarchies: can put cars or people first	Mobility and transport system factors (Mob-trans)		4/4/5
Energy for light and power: conventional, renewables	Stationary energy technology	Energy metabolism flows (Energy-flows)	Energy-flows depend on energy resources available to the city & renewables (e.g. PV)	2/3/4
Energy for transport: fossil fuels, renewable sources	Transport energy technology	Energy metabolism flows (Energy-flows)		2/3/3
Water connection: riverine or coastal topography & location	Geographic/climatic context: e.g. for design & renewable energy	Geographic and climatic factors (Geo)	Geo influences UDes, UMet, Energy-flows & UMor of the city	**5/5/3**
Climatic context of city				**5/2/4**

Group codes: Socio-economic hierarchy (SEH), Urban morphology city-wide result (UMor), Urban structural unit-precinct scale (USU), Urban fabric & design (UDes), Urban metabolism (UMet), Mobility & transport system factors (Mob-trans), Energy metabolism flows (Energy-flows), Geographic & climatic factors (Geo) *Rank in scenarios A/B/C

Scenario A

Under scenario A, the groups coded as urban structural units (USU – see glossary) and urban fabric and design (UDes) are accorded first ranking, because they influence both mobility and transport system factors (Mob-trans) and stationary and transport energy metabolism flows (Energy-flows). In particular UDes relates to Mob-trans by integrating public transport and the pedestrian network, and influences Energy-flows in the efficient siting and design of buildings, which develops the USUs. The various USUs are integrated to comprise the urban morphology (UMor) as the end result. However, UMor is accorded a second ranking, because it is not considered an overriding priority (and certainly not the existing reality) for the entire city to have sustainable development characteristics. The Energy-flows factors are also assigned a second ranking, because as revealed in Chapters 3 and 4, energy is critical to all urban functioning for both stationary and transport components. However, while it could have been considered to warrant first ranking, these cities have strong policies and programs for renewable energy, as well as the benefits of integrated public transport in compact spatial structures with medium–high density residential development. The energy and transport policies are influenced by national and regional priorities and investment, or subsidies for citywide public and private renewable energy and energy efficiency measures. This factor is considered to make the socio-economic hierarchy (SEH) a second ranking group.

Urban metabolism (UMet) is given third ranking as the variables in UDes, Mob-trans and Energy-flows determine the urban flows and stocks. This lower ranking is partly explained by the recognition that the sample cities have been developed with an inherent understanding of urban metabolic processes, but also by the evidence that cities can, and have been, built disregarding them. The mobility and transport system factors (Mob-trans) are also assigned third ranking as being important, but they are critically dependent on Energy-flows. The types and extent of public transport are determined by the urban public policies and investments that may be determined by the socio-economic hierarchy (SEH) factors beyond the city boundaries at regional or national scales. Mob-trans factors also have inter-urban and international relevance. The movement and mobility hierarchies are ranked slightly lower because the historical development of the cities has constrained the design of evolving transport networks that may put cars or people first in different precincts. However, the traffic congestion and inefficiencies are accepted as the offsetting factor to a higher priority of preserving the aesthetic values of the urban fabric.

The geographic and climatic factors (Geo) are given lowest ranking, only because they are part of the context of the historical city development and over time have been overridden by evolving technology. In the future their importance is anticipated to increase in scenarios B and C.

Scenario B

Under scenario B, the rankings are considered to make SEH, UMet (energy efficiency in buildings) potentially more important as climate change context Geo related factors accelerate. However, a warming climate in Europe would also reduce insulation and heating costs for buildings as a beneficial unintended consequence. If the smart city renewable energy and efficiency policies continue, these impact risks could be offset or managed. In any case the energy programs could be anticipated to improve the Mob-trans factors for both stationary and transport elements. It is considered that the overall first ranking of the USU and UDes groups will remain the most important in relation to the other groups.

Scenario C

Under scenario C, the rankings are considered to change as oil depletion accelerates to make the UMet factors more important for these cities as the embodied energy and transport related factors of building materials and petrochemicals increase in priority. If smart city renewable energy and efficiency policies continue, the energy programs could be anticipated to improve the Energy-flow factors for the stationary energy element. The transport Mob-trans factor is considered on balance to remain in the same rank, because of the existing public transport systems and electrification of vehicles offsetting the deteriorating oil supply situation for private transport. Moreover, the geographic context of any city will become more important, for instance as a riverine or coastal city for water transport. If the oil constraints result in decreased CO_2 emissions and serve to mitigate climate change, that component of the Geo factor will improve to a fourth place ranking. It is considered that as in scenario B, the overall first ranking of the USU and UDes groups will remain the most important.

Core variable/category

The last step in the open coding process is to establish a core variable/category. According to Glaser (2004: 10) it can be 'any kind of theoretical code … to integrate the theory'. It reoccurs frequently in the data, is central to, and relates to most of the categories and their properties. For the purpose of the core scenario A, the categorisation of the coding suggests the core variable is a combination of USU and UDes that is expressed as *sustainable urban form*, as developed in section 2.1.2. Urban morphology is not considered to be a candidate, because although it integrates the USU, UDes and UMet, it is a descriptor of the spatial structure, rather than a key variable in the development of urban fabric. The urban morphology could be across the entire range of sustainable to completely unsustainable development.

The core variable is also relevant for the purpose of the forward looking scenarios B and C, but would be interpreted differently in the case of oil sufficiency compared with the case of oil constraints. The continued GT analysis will conceptualise the theoretical sampling of those variables that relate to the core variable in significant ways.

6.2 Qualities of sustainable cities

The next GT step is undertaking axial coding of data in relation to those variables that relate to the core variable in significant ways, to articulate 'a smaller set of higher-level concepts' (Glaser 2004: 10) to conceptualise the qualities of sustainable cities. Given that the empirical knowledge relates to scenario C, the coding is framed around the following questions (Strauss & Corbin 1998: 85) in the context of the European and other cities:

a. How might the urban fabric reduce dependence on oil?
b. What features of these cities contribute to an efficient urban metabolism?
c. Overlaying these aspects, how do these cities perform in providing suitable housing and facilitate mobility of people and transport of food and goods to facilitate social and commercial intercourse (see urban form definition in 6.3.1)?

6.2.1 Urban fabric and housing that reduces oil dependence

In many of the studied old cities there is a remarkable consistency in the residential buildings. Paris is the exemplary city (Figure 6.1a), having a notable uniformity in the apartment building facades and heights that creates a harmonious streetscape, which mostly escaped World War II damage (Sutcliffe 1993: 161). This effect was largely the result of building regulations of 1783-4 and later amendments under Baron

Haussmann in the 1859 comprehensive building code. These codes set the cornice height in accordance with street width and effectively allowed up to six storeys to the cornice, with one-two attic levels (often for servants) in a mansard roof (Sutcliffe 1993: 91). This angled roof line maintained sunlight in the street below. During his 1853-1870 era of redevelopment Haussmann dictated the standardisation of building style along the new wide boulevards (over 20 m in width). The new code permitted the cornice to extend to 20 m above ground level, thereby adding a seventh storey (Ayers 2004: 399). High land values engendered by the Haussmannic property boom and aesthetic dictation by planning inspectors ensured continuous building facades to the maximum height roof (Sutcliffe 1993: 86). Ayers (2004: 398-9) suggests that the mid-1800s industrialised, mass produced building form made for middleclass renters using standardised windows in dressed limestone and stucco facades tended to greater homogeneity. He also notes the use of industrialised glazing, and in the late-1800s the introduction of the lift that allowed increased storeys above the cornice with elaborate dormers and terraces for what became the best apartments (Ayers 2004: 400). What is not evident from street level is the form of such perimeter blocks that incorporate light wells or courtyards to improve health and ventilation in the apartments (Figure 6.1a).

These Parisian building design principles can be seen in other European cities including the Vienna Ringstrasse (Figure 6.1b). In Amsterdam the style of building is different and individual residential buildings have narrower frontages, but the overall effect of joined up street facades is prevalent along the canals and streets (Figures 6.1a and 6.1c). A similar effect is evident in German city centres including Aachen, Bonn and Heidelberg. It is also a feature of southern cities such as Florence in Italy and Seville in Spain. In most cities visited it was evident that the perimeter block apartment complex is an adaptable design, which facilitates an active street frontage for commercial and retail uses mixed with the residential function, while having a flexible internal common open space. Newer twentieth century slab blocks replace the perimeter block as parallel blocks with inter-building garden and parking space, which can be problematic by being underused and unsafe (Lestan 2013). The modern Vauban Quartier of Freiburg im Breisgau, Germany has a variation on this design where the ground floor units at the street end of the oblong apartment blocks have a flexible arrangement and sheltered overhang to facilitate an active space (**Figure 6.3**). In contrast, two PassivHaus projects at Bahnstadt, Heidelberg and in Munich have no such design features, being purely residential blocks as shown in **Figure 6.4**. It should be possible to modify these designs as a substantial retrofit.

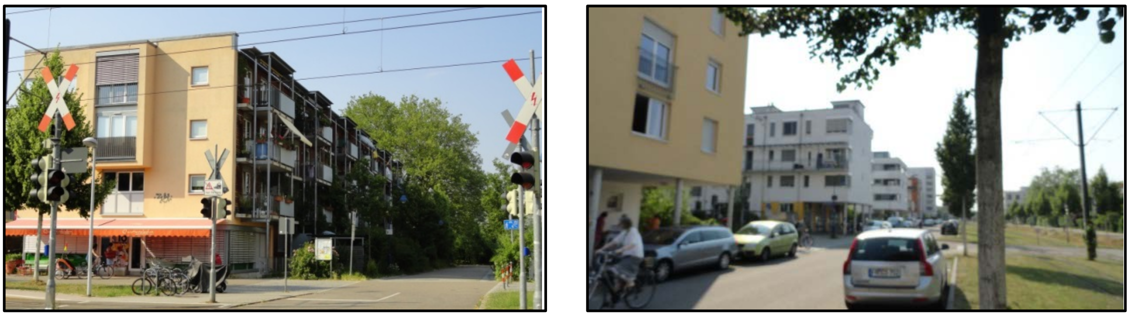


Figure 6.3: Apartment buildings in Vauban Quartier of Freiburg im Breisgau
showing activated street frontages to the main tramway street—Vauban Allee
Source: Photos by the author July 2013

Figure 6.4: PassivHaus apartment projects in Heidelberg and Munich (right)
Source: Photos by the author July 2013

The relevance to an oil-constrained environment is that in these compact cities, land is used more efficiently and the gross urban density of the building fabric increased. Central Paris is the prime example of being the most densely populated city of more than 1,000,000 in the Western world averaging 21,000 people per km^2 (210 per ha) density in the central city (Insee 2013). Figure 6.1 photos show limited, if any, building setbacks in the pre-car horse carriage and pedestrian era. Wide tree lined boulevards are a feature of Haussmann's Paris and the Vienna Ringstrasse that accommodate cars. But the uneasy invasion of cars into the narrow streets—bringing air pollution, noise and congestion—is discouraged within the Viennese old city, as it is in parts of Florence, Heidelberg, Salzburg and Zurich by traffic controls (and in London by the congestion tax). In many cities the squares and plazas form the public meeting and eating places as well as open space elements featuring trees, monuments and fountains. They add legibility and diversity to the city fabric, as do churches and public buildings sited on plazas. The urban form in these cities is not geared around cars, but walking precincts. The addition of public transport into the historic urban structures, as indicated in Table 6.1, demonstrates their adaptability, and facilitates an inner city lifestyle with a high level of urban amenity. The forms of active and public transport are elaborated in section 6.2.3.

There are of course alternative building designs such as separate towers that could achieve a similar or even higher net density. These types are prevalent in the Gold Coast areas of Broadbeach, Southport and Surfers Paradise, the case study D tower being one such example. A residential tower above a commercial podium could also have an active street frontage. However, the medium rise/high density Paris style block is considered to be more economical and flexible and requires less concrete in its construction, as shown in case study C. In a warming climate such buildings sited close to the street frontage provide more shade. Relevant southern European examples visited include Florence and Siena in Italy; Barcelona and Seville in Spain. Conversely, street trees can effectively reduce solar load on the building walls (Potes et al. 2013). The building is more flexible in use, as indicated in Figure 6.3, because the whole frontage is not constrained to be commercialised, as in a podium arrangement. However, it is possible to erect an awning or colonnade along the street frontage and also to set back the upper levels, as in the Paris mansard roof examples, to decrease the visual impact. Balconies or garden rooms can either face the street for more surveillance, and/or face the rear garden-courtyard areas. Other advantages of medium rise (4-8 storeys) buildings include opportunities for large scale modular and off-site component manufacture, and the use of structural timber to replace steel reinforced concrete; both of which are impracticable in a high rise tower. Elongated or joined up buildings can provide the backdrop to a 'green' street and may also incorporate green walls and green roofs as in the Paris examples in Figure 6.1a. Such buildings also facilitate rooftop solar PV for local power generation. The overall insight gained in the pre-oil economy European cities is that the reversal of car dominance offers positive opportunities to revert the urban form toward a people-dominated environment.

Six contemporary European examples of urban renewal lend support to the preference for medium rise development. Two of these are the already noted Vauban Quartier of Freiburg im Breisgau and the Bahnstadt redevelopment in Heidelberg, shown in Figures 6.3 and 6.4. Vauban is a 38 ha site redeveloped for 5,000 residents in some 1,400 housing units and 600 student rooms. The housing is predominantly in the form of two-level maisonettes as lower and upper units, without lifts, in 13-15 m high building configurations along Vauban Allee street. More conventional apartment buildings are 5-8 storeys for groups of building-owners and investors. Vauban is complemented by the older and larger district of Rieselfeld in the western edge of Freiburg. Construction started in 1994 to accommodate 10,000-11,000 residents in a mixed use medium density urban form comprising 3-5 storey apartments on a 70 ha city owned site. The building developments are mainly parallel block layouts with internal common garden space, interlinked to adjoining blocks. The area is linked to the city centre by an extension of the main tram route. Energy efficiency is a key requirement of both developments. All the housing units meet the Freiburg low energy standard of 65 kWh per m^2 per annum and many are energy positive—generating more electricity than consumed (Donn, T 2013, strategic planner interview 10 July).

The Heidelberg Bahnstadt is a 116 ha rail freight depot redevelopment for 5,000-6,000 residents. It features some 2,000 apartments and student accommodation in a range of building heights of 4-6 storeys (Figure 6.4), all constructed to PassivHaus energy consumption standards of 15 kWh per m^2 per annum. Officially opening in

2013, Bahnstadt is claimed to be one of the biggest PassivHaus sites in the world (City of Heidelberg 2013: 3). An inspection of the development revealed the buildings are conventional steel reinforced concrete structures and 150mm poured or block concrete external walls, with 280 mm thick expanded polystyrene foam overlays and texture coating, ceramic tile or timber cladding. The embodied energy of the buildings is therefore similar to the case study C six storey apartment building, plus the additional embodied energy of the oil/gas-based foam insulation layer. Alternative structural materials, such as timber, could have been used, having equivalent insulating values. All the apartment buildings are in large perimeter blocks and resident parking is provided in underground parking garages on individual lots. The Bahnstadt residential form is a modern equivalent of the apartment perimeter blocks of the late-1800s and 1900s in Heidelberg, which are similar in height and style and, like Paris, were spared from destruction in World War II. It therefore aligns with the historical cultural identity and physical pattern of the city's urban morphology, thereby increasing the social acceptability of this type of transformative low energy urban environment.

A similar style of development on a smaller scale is located in Munich, Germany at the Ackermannbogen development site in the north-west sector near the Olympic Park. One of the PassivHaus buildings under construction is shown in Figure 6.4. Several building companies are involved in the project, but the common theme is the low energy insulated apartment building design in a range of 4-6 storeys grouped in a dense urban pattern. Some apartments extend from front to rear of the buildings and are in conventional reinforced concrete structures similar to the Bahnstadt development.

On a much larger scale, a new city quarter in the making for Vienna is the Aspern project, designed as a multi-functional urban area on a 240 ha site 6 km east of the city (**Figure 6.5**). It is planned to accommodate 20,000 residents in 8,500 residential units, complete with a town centre, commercial uses and science campus (City of Vienna 2008a).

Figure 6.5: Architectural concept of Aspern-Seestadt urban area

Source: City of Vienna (2008b)

The new city quarter housing is intended to be in the form of apartments as a mix of building heights and densities, in ranges of 3-5, 4-7, 6-9, 8-12 storeys, with 10+ storey high rise landmarks as indicated in Figure 6.5. However the predominant ranges are those in the 4–9 storeys (orange and red zones), arranged around garden courtyards and promoting flexible uses at ground level, as shown in **Figure 6.6** taken from the master plan executive summary (City of Vienna 2008a: 14-16). Vienna has an historic culture of medium rise apartment buildings, as the main form of the 50 per cent of city owned and social housing so—as in Heidelberg and other cities—there is a high degree of acceptance of this urban form (Hartmann, S 2013, strategic planner interview 5 July). Mixed use development is promoted in commercial parts of the quarter, with taller buildings nearer the U-Bahn stations. Staggered building heights draw inspiration from the London Greenwich Millennium Village development (**Figure 6.7**) to add diversity and opportunities for rooftop terraces and gardens (City of Vienna 2008a: 17). The Aspern concept is considered to be a more spacious, modern version of the old city development with boulevards, squares and parks that illustrates the design considerations outlined above. It echoes the urban pattern of streets and squares seen in the old city and in others shown in Figures 6.1 and 6.2. The streets have short sightlines to add interest to the walking experience (Gehl 2010: 127). While these features may seemingly have little to do with oil dependency or depletion, they are important factors in creating an urban form conducive to a car-free, oil-free lifestyle.

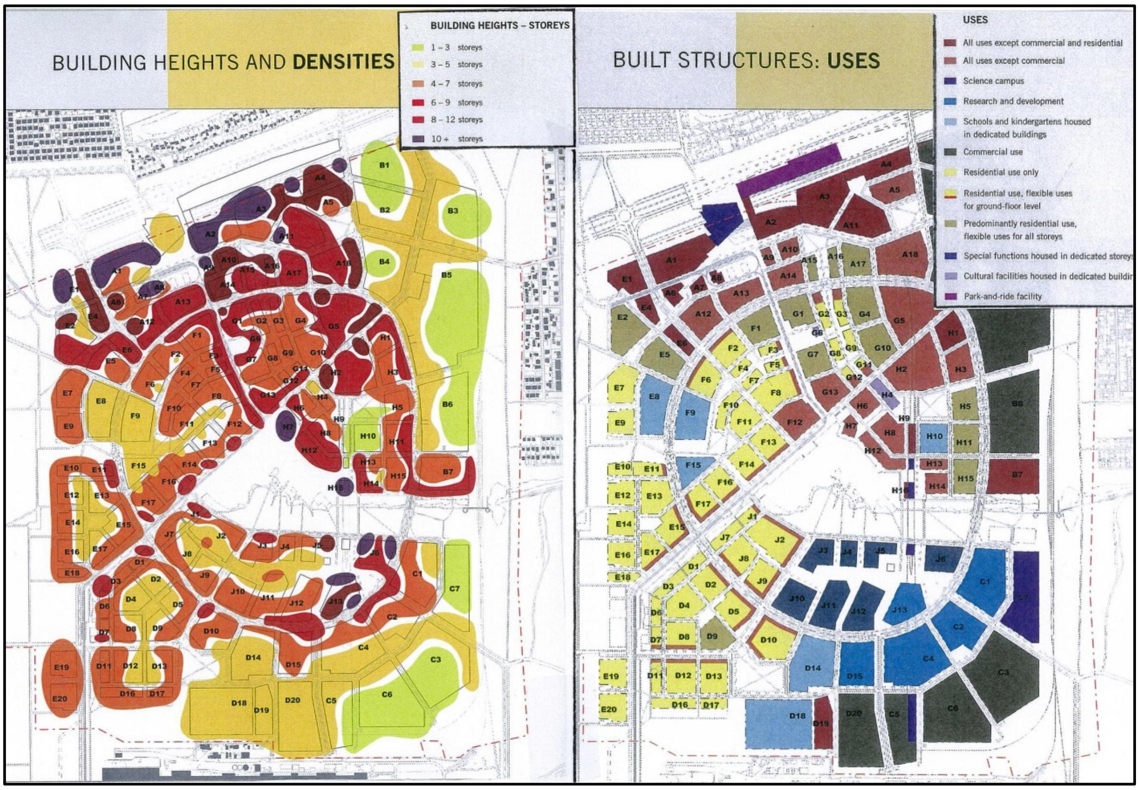


Figure 6.6: Aspern-Seestadt master plan indicative building height and types:
3-5 storeys (yellow), 4-7 storeys (orange) 6-9 storeys (red), mixed residential (yellow/red edge)

Source: City of Vienna (2008a)

Figure 6.7: Greenwich Millennium Village, London showing multi-height apartment buildings and the village square commercial centre on the right

Source: Photos by the author July 2013

In comparison with Aspern, Greenwich Millennium Village is much smaller at only 1800 dwelling units, although the master plan shows much greater potential. The photos at Figure 6.7 show the style of the 5-9 storey northern buildings, which enclose a large courtyard garden space. The 2007 master plan at **Figure 6.8** (Countryside Properties PLC 2013) shows a familiar pattern of urban residential form at the block scale as in pre-oil economy cities such as Paris, Freiburg, Heidelberg and Vienna—the enclosed perimeter block. The master plan has been revised, but still indicates a preference for both medium rise/high density apartments and an open perimeter block layout; some buildings having activated ground floor mixed uses. The project is designed as a walkable urban village linked by buses to the nearby underground station.

Figure 6.8: 2007 master plan of Greenwich Millennium Village, London showing typical apartments buildings in enclosed perimeter block type urban form

Source: Countryside Properties PLC (2013)

These urban renewal and extension projects exemplify the new wave of low energy, low carbon, smart city, residential accommodation. They stand out from detached housing estates. Although they do not prohibit cars, these urban villages and Aspern new town promote and prioritise active and public transport mobility. The Greenwich Millennium Village photos in Figure 6.7 show that medium rise/high density apartment buildings can be designed to be distinctive as well as homogeneous in appearance. The existing stages of the village are all sold out (Countryside Properties PLC 2013), which supports the proposition that they are an accepted type of urban residential development in the London context. It will be instructive to see how well the PassivHaus Bahnstadt project current stages are accepted in the Heidelberg market.

Categorisation of axial coding: urban fabric that reduces oil dependence

Axial coding of this section is in tabular form at **Table 6.3** to assess the relevance of the identified themes relating to urban fabric and housing that reduce oil dependence to the open coding groups that were established in Table 6.2. The simple ordinal axial coding ranking is discussed and compared with the other themes in section 6.3. The second theme in section 6.2.2 relates to achieving efficient urban metabolism.

Table 6.3: Categorisation of axial coding: urban fabric to reduce oil dependence

DATA	**Relevance to open coding Groups* (Table 6.2): H = high; M = moderate; L = low NA = not applicable**							
Summary of themes	**SEH**	**UMor** (city)	**USU** (precincts)	**UDes**	**UMet**	**Mob-trans**	**Energy -flows**	**Geo-climate**
Consistency in shape and size of res. bldgs	NA	M	H	H	M	M	H	L
Perimeter block apartmts	NA	M	H	H	H	H	H	L
Medium rise 4-8 storeys a common height range	NA	M	H	H	H	H	H	L
Residential tower suitable	NA	M	H	H	H	H	H	L
Comprehensive bldg codes control design	L	H	H	H	H	H	H	H
Energy efficient bldgs	M	L	M	H	H	M	H	H
Light wells/courtyards	NA	M	H	H	H	NA	H	L
Mass produced bldgs	L	L	M	H	H	L	H	L
Adaptable bldg design	NA	H	H	H	H	H	H	M
Facilitate active frontage	NA	M	H	H	M	H	H	NA
Continuous street façade, harmonious streetscape	NA	H	H	H	M	H	M	NA
Compact, dense dlpt.	M	H	H	H	H	H	H	M
Tree lined wide streets	NA	H	H	H	H	H	M	M
Limit cars in narrow Sts	NA	H	H	H	H	H	H	L
Plazas-seats, monument fountain features, trees	NA	H	H	H	H	H	M	H
Plazas add to legibility	NA	H	H	H	L	M	NA	NA
Diverse mixed-use cities	H	H	H	H	H	H	H	H
Cultural acceptance	NA	H	H	H	H	H	H	L
Relevance totals H/M/L	**1/2/2**	**10/6/2**	**16/2/0**	**18/0/0**	**14/3/1**	**13/3/1**	**14/3/0**	**4/3/8**

***Groups:** SEH (Socio-economic hierarchy), UMor (Urban morphology city-wide result), USU (Urban structural unit-precinct scale), UDes (Urban fabric and design), UMet (Urban metabolism), Mob-trans (Mobility and transport system factors), Energy-flows (Energy metabolism flows), Geo (Geographic and climatic factors)

6.2.2 Urban forms for efficient urban metabolism

While the theoretical concept of urban metabolism was introduced in the late twentieth century, the old cities of Europe and elsewhere have practised the principles to some degree and contended with constraints on resource input of materials for building construction since ancient times (Lewis 2008: 48-49). Surveys of Western architectural history after the Roman period—with the notable exception of the Paul Oliver Vernacular Architecture Library (POVAL 2013)—tend to focus on monumental buildings (e.g. Jordan 1969: Sutton 1999) and not on commodity housing. Hence there is limited data on buildings that comprise the bulk of the urban form and constitute most of the vernacular architecture. The urban metabolism as such, was framed around 'primitive' technologies in the material inputs, with minimal waste or polluting substances, apart from the end products of wood and later coal burning. That is not to say that the building stock lacked in quality or craftsmanship prior to the renaissance. Efficient use and recycling would be endemic, because of the cost of extracting, refining and making anything in terms of both technology and labour (Lewis 2008: 46-82). Cities generally were small and surrounded by a productive supporting hinterland, which supplied food and most other commodities until the age of seafaring exploration and colonisation in the renaissance and reformation periods (Mumford 1961: Chapter 4). The urban metabolism boundaries of the ecological footprint would have greatly expanded during this latter period through wider importation of materials and goods.

As an illustration, urban streets since Roman times have been either paved with bricks, cut or cobbled stone, or just left unsealed until the advent of bitumen and coal tar seal in the nineteenth century (Lewis 2008: 268). The so-called 'alternative' natural building materials used in modern 'eco-housing' reflect the vernacular construction of primitive societies, medieval and pre-industrial revolution cities (e.g. Inoue 1995; Kennedy et al. 2002; Roaf 2007; Mola 2011: 6). These materials include stone, brick, concrete, rammed earth, timber, cob and straw/thatch roofing. The industrial revolution started in Great Britain and Europe in the mid-1700s and accelerated through the 1800s in the coal-driven economy (Lewis 2008: 64-70). The coke smelting of cast iron in the 1700s and Bessemer conversion of iron to make steel in the late 1800s revolutionised city building (Lewis 2008: 64-68). Prior to this period, iron was an expensive material and had been used sparingly in buildings, the exception being various types of wrought iron nails. Nail making was a laborious process of the blacksmith trade, but the invention of machine-made nails in the early 1800s at low cost enabled timber framed structures to be constructed quickly and easily without joints (Lewis 2008: 67). The widespread use of structural steel in the 1890s led to the rise of the American skyscraper in the pioneering Chicago school of architecture by the late-1800s and in New York in the early-1900s (Lewis 2008: 72-73). As European cities expanded in the twentieth century and particularly in post-World War II reconstruction, the urban metabolism became much more complex for both inputs and outputs. This resulted in outputs. This resulted in the scientific approach overviewed in Chapter 3 of this thesis.

Case study A suggests that from an embodied energy viewpoint, detached houses are the most energy efficient form and can involve the least complicated construction processes. However, Chapter 2 considers the low density of mainly detached housing estates causes an inefficient use of land, which requires more roads and engineering services, and results in suburban sprawl. This applies even to the quintessential new urbanism projects Seaside and Celebration in Florida, USA. The focus on individual low density 1-2 storey houses is evident in guide books on 'natural' architecture and even in showcase examples of super-efficient PassivHaus construction projects (e.g. Kennedy, Smith & Wanek 2002: 243-274; Roaf 2007: 330-457; Mola 2011; International Passive House Association 2013). Such architecture lacks the compactness of the European cities prior to 1900s and is more at home in the suburban and peri-urban environments of architects Frank Lloyd-Wright and Alvar Aalto. The Aspern, Freiburg and Greenwich examples overviewed above demonstrate a different pathway to a sustainable future that is more in tune with an oil-constrained scenario. This view is reinforced by interviews with city government planners in Aspern and Freiburg presented below.

An interview with a strategic planner of the Vienna municipal council planning (Stadtplanung) department about the Aspern development confirms it is a project in the Smart City Wien 2050 program and the transformative strategic agenda (Hartmann, S 2013, interview, 5 July). The aims include low energy development with affordable housing, and public transport usage increasing from 40 to 80 per cent by 2020. A *Roadmap 2020 and beyond strategy* framework is expected to be adopted by the city parliament to start implementation in 2014, extending beyond the inner city to the new main rail station area and the new growth centres including Aspern. The targets focus on 50 per cent renewable energy, especially for heating and cooling, to assist in achieving an 80 per cent carbon reduction by 2050. Such changes affect the urban metabolism in positive ways for both energy inputs and CO_2 and other pollutant outputs. The roadmap includes issues of construction and refurbishment of buildings. It is considered by the city that in the Austrian climate and environment, brick construction is the best form of construction and will reduce the cement consumption.

In Zurich, a city administration expert in energy policy (Brunner, F, interview, 8 July 2013) discussed the Swiss approach to energy efficient buildings and the goal of a '2000 watt' society. Switzerland relies on 60 per cent hydro and 40 per cent nuclear power, which are publicly regarded as a 'free' form of clean energy. Hence a strong public awareness campaign is necessary to link energy consumption with CO_2 emissions. Petroleum is used to heat buildings (one third) and in transport (one third), which is relevant to both housing and mobility. New buildings are encouraged to be equivalent to the PassivHaus standard of construction to assist in improving the energy element of the urban metabolism. The target is to achieve a low 2000 watt per person per annum continuous power consumption plus only one tonne CO_2 emission by 2050. The 2000 Watt Society (Püntner, T 2013, interview, 12 July) advocates including building embodied energy and transport energy consumption, as well as food production energy in the standard. It therefore involves more than just operating energy. A driver of this policy is the decision taken by referendum to close all five nuclear power plants by 2050. Pricing policy is favoured over a voluntary mechanism, because of the slowness in making the transition to a low carbon society.

Two projects for urban renewal—Sihlbogen for 250 apartments and Stadt Bau district in Zurich North—are designed to limit car ownership by providing no parking spaces (or parking basements), making housing contract agreements to not own a car, but to use car sharing schemes. These projects also use geothermal and bio-mass district heating instead of gas fired water boilers. New building standards allow steel or concrete cores with reinforced structural timber. Private consultants are also innovating the refurbishment of older housing to a low PassivHaus energy standard by installing substantial 200-300 mm insulation cladding, solar thermal and PV systems and triple glazed window units (Schulte, G 2013, interview, 14 July). However, this is more applicable to a cold climate. One or more additional storeys are a means of densifying buildings where allowable, to reduce the renovation cost per dwelling unit.

These few examples give an indication of the commitment by the city to reducing the energy element of urban metabolism. The point being made here is that the reduction of energy inputs has positive benefits for energy production and greenhouse gas emissions, noted in section 3.2, as well as economic benefits in lowering consumption. Energy inputs include transport energy, which is addressed in section 4.1.3. The urban residential form can influence the trajectory of energy efficiency in the ways described in the examples above. While the focus is on the old cities, new developments within some of those cities are at the forefront in compact, efficient design at the building and precinct levels of the morphology. Such examples are in a medium density-medium rise configuration and not in low density urban sprawl.

A significant challenge is considered to be the cultural paradigm shift needed to support ecologically regenerative urban design. An encouraging sign is the willingness of ‘Generation Y’ young adults and ‘millennial’ generation teenagers to forego personal mobility through cars, in favour of social networking enabled by the digital environment and facilitated by use of digital devices in public transport (Foth 2011). Foth considers that digitally connected communities (of interest) are still tied to life happening in a physical place. These places are essentially the vibrant inner urban areas that have qualities of ‘a continuous, well connected, open place, conducive to development’ (Lynch 1984: 235), epitomised by some of the old cities of Europe and elsewhere, and being emulated in many modern cities in the developed world.

In a study of high density cities, Brenda and Robert Vale (2010) also look to the old cities such as those discussed above, as models to reduce the ecological footprint and improving urban metabolism in a resource-constrained future. They suggest that the sustainable use of resources will be ‘one resource supporting many functions, as in the vernacular settlement’ and cite the adaptable design of medieval cities (Vale & Vale 2010: 19-20). The high density city is not likely to be tenable under a collapse scenario, for reasons offered by the authors in terms of food security, energy supply and waste management. As an example, an ecological food footprint for a typical western diet in Canada or UK requires about 1.3-1.6 ha of productive land per person (Vale & Vale 2010: 21). A western city like the Gold Coast—with an animal-based high protein diet—is equally dependent on a large hinterland. Even at 1.5 ha per person, the city would require a productive area of some 1,200,000 ha or 12,000 km^2 for a population of 800,000 (by 2031) (Queensland Treasury & Trade 2013: 11). The city area is 1,333 km^2 including national parks and forests. Hence the city could not feed itself on this basis without vast imports of foodstuffs. Conversely the carrying capacity of the city land for growing food is less than 90,000. Even this would require all available backyards and non-urban land to be converted to agriculture/horticulture, including the extensive rainforests and the sugar cane lands on very poor soils. Alternatively the sugar cane could be the main source of ethanol for transport fuel to assist in importing food from the hinterland. Exploiting the opportunities for urban farming would be an essential part of the transformation to future sustainability. Community gardens are common in Europe and are increasing in Australia, as shown in **Figure 6.9** in Tours, France and Melbourne, Australia. These opportunities can be designed into the urban fabric, or retrofitted into schools, parks and on vacant land as a temporary use. Green roof gardens and high rise 'farms' are an architectural solution to growing food in dense city areas, as advocated by Yeang (2002) in reinventing bio-climatic skyscrapers.

Figure 6.9: Community gardens in Tours, France and Melbourne, Australia

Source: Photos by the author July 2013

Greening of the urban areas is also linked to the concept of creating 'low carbon' or 'green' streets, as an emerging land use and transport planning strategy for reducing car use and improving transport sustainability. The purpose of a Green Street is 'to enhance and expand public open space, and to reinforce desired land use and transportation patterns on appropriate City street rights-of-way' (City of Seattle 2005). Notable cities implementing this concept are Paris, Copenhagen and Zurich in Europe, Vancouver in Canada, Portland and Seattle in the USA. The treatments may include sidewalk widening, edible landscape, traffic calming, and other pedestrian-oriented features that reduce the amount of street space and hard pavement for car parking.

In summary, efficient urban metabolism is evident in adapted sustainable cities by a combination of vernacular design, material stocks, food and energy flows from a productive hinterland, which in modern cities rely on oil and gas based inputs. Some features are directly linked to the built environment and reflected in the urban form, such as architectural and engineering infrastructure. Other features have an indirect connection, such as replacement of foam insulation by traditional materials, local intensive agriculture in urban and hinterland areas, and low energy mobility systems linked to green streets and a network of public plazas and parks. The mobility of people and transport of food and goods is discussed in section 6.2.3.

Categorisation of axial coding: urban forms for efficient urban metabolism

Coding of this section is in tabular form at **Table 6.4** to assess the relevance to the open coding groups, established in Table 6.2, of the identified themes relating to urban forms for efficient urban metabolism. The axial coding is discussed and compared with the other themes in section 6.3. The third theme in section 6.2.3 relates to mobility.

Table 6.4: Categorisation of axial coding: efficient urban metabolism

DATA	**Relevance to open coding Groups* (Table 6.2): H = high; M = moderate; L = low NA = not applicable**							
Summary of themes	**SEH**	**UMor** (city)	**USU** (precincts)	**UDes**	**UMet**	**Mob-trans**	**Energy -flows**	**Geo-climate**
Historic urban metabolism in resource conservation	L	H	H	H	H	L	H	M
Vernacular architecture and building materials	L	H	H	H	H	L	H	H
Importation of goods	M	M	M	M	H	L	H	H
City ecological footprint	M	H	H	H	H	M	H	H
Productive hinterlands to support city population	M	M	L	L	H	H	H	H
Technological innovation and inventions	H	H	H	H	H	H	H	M
Reinforced structural timber in med rise bldgs	M	L	M	H	H	H	H	H
Brick bldgs to limit cement	NA	L	M	H	H	NA	H	H
Detached houses as an efficient energy form	NA	H	H	H	H	M	H	H
Limit new low density dlpt.	L	H	H	H	H	H	H	L
Energy efficiency – 2000 watt /person/yr goal	H	L	M	H	H	H	H	M
PassivHaus standards for low energy consumption	L	L	M	H	H	L	H	M
National targets for renew. energy (e.g.50 % by 2050)	H	M	H	H	H	H	H	H
Limit car ownership by contract and parking	L	H	H	H	H	H	H	H
Food security policies	H	L	M	M	H	M	H	H
Urban farming/highrise farms/community gardens	L	M	H	H	H	M	M	M
Green roofs/walls	NA	M	H	H	H	L	M	M
Low energy mobility	L	M	H	H	H	H	H	M
Relevance totals H/M/L	**4/4/7**	**7/6/5**	**11/6/1**	**15/2/1**	**18/0/0**	**8/4/5**	**16/2/0**	**10/7/1**

***Groups:** SEH (Socio-economic hierarchy), UMor (Urban morphology city-wide result), USU (Urban structural unit-precinct scale), UDes (Urban fabric and design), UMet (Urban metabolism), Mob-trans (Mobility and transport system factors), Energy-flows (Energy metabolism flows), Geo (Geographic and climatic factors)

6.2.3 Mobility, transport and function in sustainable cities

A general feature of many old mono-centric cities is that the central areas exhibit the highest development densities and tallest buildings, some of which are products of the oil economy period. The future transformation of such central areas will continue to build on the past development, as in Frankfurt—rebuilt after World War 2. In other cities the historic heart ('Altstadt' in Germanic countries) is preserved at lower densities, partly because of the civic and religious buildings in plaza settings, as in Aachen, Bonn, Cologne, Florence, Seville and Utrecht. In those cities new central city functions are located in adapted buildings, or adjacent to the old city centre. The electrified light rail, underground and bus-based public transportation systems that were developed in the 1800s, or retrofitted and embedded in the urban fabric, are an important consideration in the efficient functioning of old cities and their newer inner and outer suburbs. The systems in most of the old European cities visited generally converge on or near the main rail station, which links the city to the extensive regional, national and international rail networks. This focus is both convenient for visitors and efficient for residents with strong central city employment. European examples include large cities such as Amsterdam, Cologne, Frankfurt and Zurich. Smaller European cities include Aachen, Bonn, Freiburg, Heidelberg, Orléans and Seville. In some cities, such as Seville and Florence, the main rail station is not so closely integrated with the central public transport system, because the urban form could not be adapted to facilitate it.

In polycentric metropolitan regions, the transport systems are necessarily more diffuse to handle the volume of passengers. European examples include London, Milan, Munich, Paris and Vienna, all of which have multiple mainline stations and efficient underground metro and surface light rail systems. Many other global cities have similar systems. The fact that they are all electrified future-proofs the cities with respect to passenger transport. Vienna old city has a new fleet of all-electric buses operating as of July 2013, which can recharge from the overhead tram lines (European Commission 2013). Other cities have compressed natural gas powered or electric-hybrid buses as an alternative energy source. Zurich has S-Bahn, trams, buses and electric trolley buses in a closely integrated system. Such systems could facilitate building worker transport. Apart from the integration of public transport modes, mobility in the old city centres is greatly facilitated by the proximity of living, working and shopping accommodation. Traffic congestion is managed in different ways—in some cities by taxing (e.g. Transport for London 2013); in others by low speed controls, parking restrictions, or environmental regulation (Zurich and Munich). Since October 2008, Munich has a low emission zone to control access into the city centre (City of Munich 2013).

A radically different approach to congestion management is simply to allow it to occur and act as a strong disincentive to using private transport in the inner city (OECD 2007, City of Toronto 2013). This strategy can be effective in the old cities having excellent public transport systems, because the alternative transport is convenient and efficient. However, it was seen in many old cities, including central

Paris and Rome, Japanese and African cities that traffic congestion is a way of life. On the other hand, cities such as Amsterdam; Barcelona; Aachen, Bonn, Heidelberg and Würzburg altstadt in Germany, Leicester in UK; Montmartre and Orléans in France, Lucerne and Zurich in Switzerland have extensive shared traffic-pedestrian zones with limited or no on-street parking (Figure 6.1b). These streets and plazas are pleasant places to be in and walk through. Personal mobility in these places was assessed by the to be such that the new urbanism target of a five minute walking zone could be doubled with little sense of inconvenience (Gehl 2010: 121). Combining this local mobility with timetable-free public transport for arrival and departure in the central area promotes a car-free lifestyle, even without using the bike sharing service provided in many cities. The same could not be said about walking in the big modern North American cities visited, even in Ottawa, Montreal or Vancouver in Canada; and Chicago, New York, San Francisco, Seattle or Washington DC in the USA. Much greater reliance is placed on public transport and taxis because of the large block sizes, traffic congestion and lack of restful public plazas or parks. Downtown Portland is an interesting exception, because the small block sizes of about 60–100 m square are a deliberate design feature to encourage walking at one minute per block (Armstrong, T, 2013, interview, 30 July).

North American examples of effective public transport systems in cities visited include San Francisco downtown cable cars, conventional buses and Bay Area Rapid Transit system; the Chicago public transport centred on the historic Loop elevated rail system, Portland Metro Area Express (MAX) light rail system that is highly integrated; and Seattle downtown bus system. Vancouver in Canada is exceptional, because the downtown is offset from the geographic centre at the North West shoreline of the peninsula formed by Burrard Inlet and False Creek. The centre is accessible by Skytrain elevated tracks extending east and south, which are punctuated by transit oriented high density–high rise developments around many of the stations (**Figure 6.10**).

Figure 6.10: Transit oriented nodes, Vancouver Skytrain Millennium Line

Source: Photo by the author June 2006

One outcome of dense cities, including most of those noted above, is the well documented inverse relationship between density and private car distance travelled—the higher the density, the fewer kilometres travelled and therefore less oil consumed (Neumann & Kenworthy 1999). Even in these cities, it is accepted that only a relatively small proportion of urban passenger trips may involve the heavy or even the light rail system to the centre, so that a cross-city matrix network approach to bus systems may be more efficient (Low & Astle 2009; Mees 2010). Clearly the mono-centric cities generate more such trips to the centre, which reinforce their commercial function. Polycentric cities are more diffuse. In both cases the efficiency of tram services is improved by separation from car traffic, such as in shared pedestrian streets (Figure 6.1b), or advanced priority signalling at intersections. A recent innovation similar to bike sharing is car sharing services that reduce the need for a privately owned car in the inner city lifestyle (e.g. car2go operating in 16 European and North American cities; and Zipcar in Canada, Spain, United Kingdom and United States). This is evident in several European, UK, USA and Canadian cities, the latter encouraging apartment buildings to offer a similar integrated service (Metro Vancouver 2012). For example 'San Francisco now mandates carsharing in large developments, while others such as Austin, Texas, and Vancouver reduce parking requirements for projects that include carsharing' (City CarShare 2011: 2).

Cities integrated into the regional rail system already have a functional advantage in goods distribution. One advantage of such close integration is that in the future, food and goods could be distributed at night time directly from the central rail station via the local public transport system to intra-city warehousing and shopping centres. This concept is already being experimented with on a small scale (Regue & Bristow 2012). It could involve purpose designed goods trams running on the light rail network—or just adapted trams possibly towing small freight trailers—at night time to internal distribution points, when passenger numbers are low. It is also feasible for late night suburban bus services that carry few passengers to become part of the food supply chain to shopping centres on their network routes. Zurich already operates cargo trams for waste collection (City of Zurich 2013). The cargo tram concept cannot be the only solution; hybrid electric, compressed natural gas powered trucks and compressed air delivery vans are anticipated to become important in the post-peak oil period. Liquid and pneumatic pipelines also can move continuous supplies of substances and containerised goods. The conclusion is that these alternative transport options can be facilitated by the urban form of sustainable cities to reduce oil consumption.

In his analysis of what makes cities sustainable, Gehl (2010) acknowledges the depletion of fossil fuels, and energy consumption and emissions of buildings as important issues. He focuses on transport as a key element and advocates higher priority on pedestrian and bicycle traffic 'to change the profile of the transport sector' (Gehl 2010: 105). However, he advocates more compact and transport oriented development (TOD), expressing the view that 'before the incursion of cars, old cities were all well-functioning TOD cities'; and that 'a good city landscape and good transportation system are two sides of the same coin' (2010: 105, 107). The points being highlighted are that the urban form of pre-oil economy cities offers relevant solutions in providing the foundation for a sustainable city.

The Australian National Urban Policy (NUP) also considers that 'alternative urban development forms can significantly influence transport energy use and greenhouse gas emissions. Modelling of land-use scenarios for Melbourne … illustrate the long-term benefits of a compact inner city and a small number of larger polycentric outer cities in achieving urban sustainability outcomes' (Australian Government Department of Infrastructure and Transport 2010c: 64). The NUP refers to studies by Trubka et al. (2010a and 2010b) to support the views advocating inner city redevelopment to reduce transport costs and emissions. The difference in perspective of this thesis compared with the above NUP statement is the likely impact of oil constraints on urban form—rather than just transport costs and CO_2 emissions—which leads to the selective coding of the desirable characteristics of an oil-constrained city.

Categorisation of axial coding: urban mobility, transport and function

Coding of this section is in tabular form at **Table 6.5** to assess the relevance to the open coding groups, established in Table 6.2, of the themes relating to urban mobility, transport and function in sustainable cities. Axial coding is compared in section 6.3.

Table 6.5: Categorisation of axial coding: mobility, transport and function

DATA	**Relevance to open coding Groups* (Table 6.2): H = high; M = moderate; L = low NA = not applicable**							
Summary of themes	**SEH**	**UMor** (city)	**USU** (precinct)	**UDes**	**UMet**	**Mob-trans**	**Energy -flows**	**Geo-climate**
Mono-centric cities public transport – focused	NA	H	H	H	H	H	H	M
Polycentric cities public transport – diffuse	NA	H	H	H	H	H	H	M
Retro-fit of PT systems ($)	M	M	H	H	H	H	H	M
Electric trams, S-Bahn	NA	M	H	H	H	H	H	H
Underground rail, U-Bahn	NA	L	L	L	H	H	H	H
Bus-based: CNG, elec., hybrid fuels	NA	M	H	H	H	H	H	M
Close integration of PT modes and services	L	M	M	H	M	H	H	M
Links with regional rail	M	L	L	L	M	H	H	H
P.T. for cargo transport	L	L	L	M	H	H	H	M
Traffic congestion control	NA	L	M	H	M	H	H	H
Parking restrictions	NA	M	H	H	M	H	H	H
Shared traffic-pedestrian low speed zones	NA	H	H	H	M	H	H	M
Car sharing services	NA	NA	NA	L	M	H	H	H
Bike sharing services	NA	M	M	M	M	H	H	H
Small block sizes mobility	NA	H	H	H	L	H	L	L
Plazas, parks & pleasant pedestrian spaces to meet	NA	H	H	H	L	H	L	M
10 min./1 km walk radius	NA	H	H	H	L	H	M	M
Transit oriented dlpt.	L	H	H	H	H	H	H	H
Relevance totals H/M/L	**0/2/3**	**7/6/4**	**11/3/3**	**13/2/3**	**8/7/3**	**18/0/0**	**15/1/2**	**8/9/1**

***Groups:** SEH (Socio-economic hierarchy), UMor (Urban morphology city-wide result), USU (Urban structural unit-precinct scale), UDes (Urban fabric and design), UMet (Urban metabolism), Mob-trans (Mobility and transport system factors), Energy-flows (Energy metabolism flows), Geo (Geographic and climatic factors)

6.3 Characteristics of oil-constrained sustainable cities

The result of the open and axial coding process is the emergence of eight groups as sub-categories and a core category, described as *sustainable urban form* as an amalgam of the top ranking urban structural unit and the urban design groups. The grounded theory process involves selective coding 'to find a descriptive narrative of the core variable/category, relate it to other [sub-] categories; and validate these relationships' (Gray 2009: 509). Glaser (2004: 10) suggests the selective coding should delimit the analysis to only those variables that relate to the core variable/category and continue until 'the researcher has sufficiently elaborated and integrated the core variable, its properties and theoretical connections to other relevant categories'. Sufficient saturation of the coding has established the core category. The relationships between the sub-categories and the categorised themes are established in the group coding Tables 6.3–6.5. The selective coding aims to reduce the number of categories to those that are most significant relative to the core category.

6.3.1 Core category and sub-category relationships

In examining the eight groups used in the axial coding, it appears that the urban morphology group (UMor) duplicates the urban structural unit group (USU) in most of the relevance coding. This is because they are closely related—the UMor at the citywide scale and the USU at the smaller precinct scale. Hence the UMor can be dropped out of the analysis, except for isolated important themes. Likewise the socio-economic hierarchy can be dropped out because it does not yield a significant number of important themes in Tables 6.3 and 6.5. In Table 6.4 coding of efficient urban metabolism, however, there are four key themes considered to have regional or national significance: technological innovation and inventions; national targets for renewable energy; setting energy efficiency standards; and food security policies. These themes are taken into account in the analysis in Chapter 7 applied to the City of Gold Coast. The selective coding therefore proceeds with the six remaining groups.

The original definition of urban form in section 2.1.2 to describe the physical entity of an urban area is slightly modified to describe the properties of the core category:

Sustainable urban form is a set of complex relationships comprising:

a. the framework of urban structural units in a hierarchy of scales, transformed within the emerging historical, geographical, ecological and climatic context;
b. the urban design—shape, height, density and appearance—of the built environment, including the interface between the built environment and public realm—streets and public spaces, public and private open greenspace;
c. mobility and movement hierarchies—networks and transport systems; and
d. the urban metabolism supporting, facilitating and sustaining the socio-economic functionality of a city, including social and cultural processes, metabolic flows of substances, goods, energy and communication within a regenerative ecological footprint.

The selective coding amalgamates Tables 6.3–6.5 into a compressed set of 27 relationships in Table 6.6 that validate the definition of *sustainable urban form*.

Table 6.6: Selectively coded categories and relevance to significant groups

DATA	Relevance to open coding Groups* (Table 6.2): H = high; M = moderate; L = low					
Summary of themes	**USU** (precincts)	**UDes**	**UMet**	**Mob-trans**	**Energy -flows**	**Geo-climate**
National renewable energy targets	H	H	H	H	H	H
Diverse mixed-use cities	H	H	H	H	H	H
Compact, dense development	H	H	H	H	H	M
Reduced city ecological footprint and importation of goods and food; regenerative urban ecology/farming/ highrise farms/ community gardens	H	H	H	H	H	H
Productive hinterlands support city population and increase food security	M	M	H	H	H	H
Vernacular architecture in residential building design and materials to limit cement consumption, conserve resources and to promote off-site production/manufacture	H	H	H	H	H	H
Technological innovation/inventions including building materials	H	H	H	H	H	M
Cultural acceptance of transformation in urban design and construction	H	H	H	H	H	L
Perimeter block apartments in medium rise 4-8 storeys height range	H	H	H	H	H	L
Residential towers in suitable locations	H	H	H	H	H	L
Limit new low density development, but detached houses as an efficient energy form in suitable locations	H	H	H	H	H	H
Comprehensive building codes to control design	H	H	H	H	H	H
Energy efficient buildings with light wells/courtyards, green roofs/walls as appropriate, including high insulation standards (e.g. PassivHaus) for low energy consumption	H	H	H	M	H	H
Continuous street façades, with active frontages and harmonious streetscape; small block sizes	H	H	M	H	M	M
Green street design with tree planting and a hierarchy of road widths with cars limited in narrow streets	H	H	H	H	H	M
Plazas with seating, interesting art and fountain features, trees, which create spaces to meet and add to the legibility of cities	H	H	H	H	M	M
Low energy mobility and extended walking radius to 10 min./1 km	H	H	H	H	H	M
Relevance criteria subtotals H/M/L	**16/1/0**	**16/1/0**	**16/1/0**	**16/1/0**	**15/2/0**	**8/6/3**

Summary of themes	USU (precincts)	UDes	UMet	Mob-trans	Energy -flows	Geo-climate
Transit oriented development focus	H	H	H	H	H	H
Mono-centric cities public transport – focused on city centre	H	H	H	H	H	M
Polycentric cities public transport – diffuse networks	H	H	H	H	H	M
Retro-fit of PT systems (investment)	H	H	H	H	H	M
Electric trams, S-Bahn	H	H	H	H	H	H
Underground rail, U-Bahn	L	L	H	H	H	H
Bus-based: CNG, elec., hybrid fuels	H	H	H	H	H	M
Close integration of PT modes and services, links with regional rail, possible P.T. for cargo transport	M	H	M	H	H	H
Car ownership/use limits by contract and parking restrictions, aided by car and bike sharing services	H	H	H	H	H	H
Traffic management including parking restrictions; shared traffic-pedestrian low speed zones	H	H	M	H	H	H
Relevance criteria totals H/M/L	24/2/1	25/1/1	24/3/0	26/1/0	25/2/0	14/10/3

***Groups:** USU (Urban structural unit- precinct scale), UDes (Urban fabric and design), UMet (Urban metabolism), Mob-trans (Mobility and transport system factors), Energy-flows (Energy metabolism flows), Geo (Geographic and climatic factors)

The table indicates a strong validation in terms of the proportion of themes with a consolidated ‘high’ relevance to the sub-category groups. However, caution is needed in interpreting the three-point ordinal scale, because it is not a comparison of like with like between the themes. Hence the temptation to make statistical inferences has to be avoided. Aside from that caution, the themes indicate that mobility and transport, closely followed by urban fabric and design, and energy flows, are the most significant relationships; then urban structural units and urban metabolism. While the mobility aspects are closely related to the urban form, the current public transport—and particularly underground rail—systems are the product of modern technology. The structure of some pre-oil economy cities may facilitate fixed-track public transport, but clearly many do not—e.g. in the fine-grained central parts of Vienna, Florence, Barcelona and Seville. These aspects are considered to be important in making propositions in relation to the possible future oil-constraints.

A schematic model of the completed selective coding process is adapted from Gray (2009: 512). **Figure 6.11** shows the relationships between the central category and the sub-categories in the context of oil-constrained scenario C. The central phenomenon is *sustainable urban form* that has properties and dimensions. The causal condition is oil depletion, which could be modified by those properties and dimensions affecting the sustainable urban form phenomenon to produce a desired outcome analogous to an *oil-constrained sustainable urban form*. Of course undesirable outcomes are also possible but not shown in the model, which would result in unsustainable urban forms.

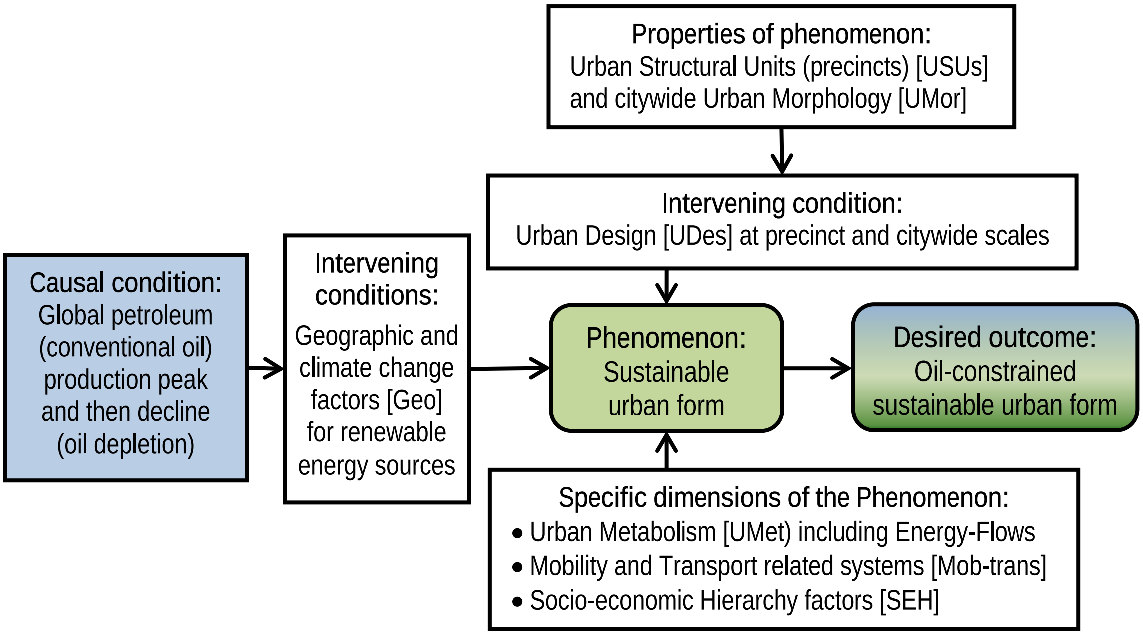


Figure 6.11: Schematic model of theoretical connections for sustainable urban form phenomenon

Source: Framework adapted from Gray (2009: 512)

6.3.2 Oil-constrained sustainable urban form characteristics

The foregoing analysis is based on the study of existing cities developed in the pre-oil economy and supplemented by knowledge of and exposure to modern cities that have different urban forms. Some cities are closer in form to the City of Gold Coast, such as Amsterdam (canals) and Portland, Oregon USA, (large suburban structure). Although the European model is considered to provide valuable insights to the future post-oil economy, the characteristics need to take into account the Queensland planning and development context, considered in Chapter 4, and the regional sub-tropical climate. While Passivhaus design is suited to cold climates, the low energy principles are still relevant. The themes identified in section 6.3.1 are a useful starting point to suggest grounded theory hypotheses arising from the analysis. Having reached this point of the analysis, the planning-related characteristics of a sustainable city under scenario C of oil constraints can be distilled into a narrative about the modified phenomenon (Gray 2009: 509) from the literature, the case studies and the selective coding relationships:

A. Urban development is contained within well-defined boundaries to facilitate densification and public transport, and outward expansion is curtailed by planning policies and public transport factors. The city-wide urban form is uniformly compact and thus conducive to active (walking and cycling) mobility for everyday activities.

B. Low density residential development is limited by planning policies, but detached houses are acknowledged as efficient energy forms in suitable locations, particularly in the outer suburban segments of the urban transect (Figure 2.5). This area is gradually transformed into a productive urban living/horticulture zone, facilitated by transferrable development rights legislation or planning codes.

C. Central and nodal activity centres are planned as integrated mixed use, three dimensional eco-architectural systems to fully exploit the residential opportunities in a range of medium rise development, while preserving solar access. Residential towers are located in suitable locations, such as at focal points and in areas of existing towers. The strategy is implemented as a planning policy in cooperation with the private development sector, and supported by public awareness through community engagement programs. Piecemeal (re)development extending from the activity nodes is avoided where possible by infrastructure scheduling.

D. Urban design planning for dense development features small block sizes, semi-continuous street façades, with active frontages and harmonious streetscape. Green street design with tree planting and a hierarchy of road widths limits cars in narrow streets. A network of landscaped plazas with seating, attractive art and water features, creates pleasant spaces to meet and add to the legibility of cities. These features promote walking and low energy assisted mobility to extend the comfortable radius to 10-15 minutes or about 1 km (allowing for street crossings).

E. Medium rise–high density apartment buildings are a preferred type of urban residential development as an alternative to detached houses. This alternative is strongly associated with a cultural acceptance of such an urban design form in European cities, but may only gradually increase over time in the Australian context, unless planning and financing policies incentivise this residential form.

F. The city is well serviced by multiple forms of public transport, including surface and underground systems, which are tightly coordinated with high frequency operation, and incorporate active modes. The land use–transport system is designed to transform effectively *most* of the city towards a public–active mobility oriented development (P-AMOD) focus that promotes and realises densification in ways that go beyond current TOD parameters. Precincts are more focused on 'place' than 'transit'.

G. Private car transport usage is reduced by oil-constraints and active transport—walking and cycling—is prioritised. Shared traffic-pedestrian low speed zones are integrated with public transport routes in central and nodal activity centres.

H. Comprehensive building codes support the innovative design of low embodied and operational energy-efficient buildings with high insulation standards (e.g. PassivHaus where climatically effective). Technological innovation and inventions include non-oil-based building materials and construction methods.

I. Vernacular architecture in residential building design and materials is promoted to use local materials, reduce cement consumption, conserve resources and facilitate off-site manufacture of materials and components. Off-site manufacture eases the transport-related labour element of construction problems and is integrated into the three dimensional eco-architectural system suggested above.

J. The city has a comparatively reduced ecological footprint by the combination of regenerative urban and hinterland ecology, renewable resource cultivation, hinterland horticulture, urban community gardens and building based farming.

In addition to these characteristics coded from the grounded theory analysis, Chapters 4 and 5 conclude that all city building is vulnerable to the effects of oil depletion to some extent. A transformed city suggests an overlay of energy and socio-economic related characteristics. While some of these qualities may not be directly planning related, they nevertheless need to be taken into account in the strategic planning transformation:

K. The case studies in Chapter 5 indicate that high rise residential towers are more embodied energy intensive forms of development, so are potentially more affected by all the effects of oil constraints on construction. Moreover, embodied energy is only one part of the energy equation. The second part is the operational energy, which has been studied in detail (e.g. Pears 2005, Ambrose 2008, Birkeland 2008, Perkins et al. 2009). In such studies, the higher operational energy from air conditioning is shown to offset the potential savings in transport energy use in high rise developments, unless or until low energy alternatives such as solar powered air conditioning are realised. The third operational energy issue relates to refurbishment, which are most costly for high rise towers (Roaf 2010: 28); and to eventual demolition, which is also most problematic for high rise towers (Roaf 2010: 28). An associated implication is the problem of social acceptance of high rise residential buildings, even at inner city locations, as noted in section 6.2.1 and revisited in Section 7.3.3. These considerations imply that high rise central city and TOD type developments may be more threatened, with negative implications for the concept of high rise oriented 'compact urban form' (e.g. Dittmar and Ohland 2004; Droege 2006; Register 2006; Newman et al. 2009; Weller 2009). It has been suggested that the peak oil plateau possibly could also be the peak of urban development. Such a notion runs counter to techno-future oriented architects who envisage vast three-dimensional cities of skyscraper towers (e.g. Broto 2010).

L. Renewable energy sources gradually make the city independent of the oil-economy both in manufacture of components and in operation of the built environment. This implies that solar and wind based powered technology eventually is capable of constructing and operating locally distributed electrical systems. Gas is used as an interim solution to fire power stations while the renewable base load systems are developed (such as concentrating solar thermal arrays in Australia). Innovation and invention in battery technology are increasingly important in the digital economy and in transportation. However, the weight penalties of battery packs make their use in long distance transport vehicles impracticable. The energy density required in heavy duty construction machinery (such as excavators) is also problematic and both cases will probably continue to rely on bio-diesel fuel.

M. The initial *mitigation phase* of oil depletion will see significant price increases for transport fuels. This will lead to prioritised rationing (or differential pricing) of petroleum products to extend the time horizon for the benefits of the resource and provide oil-based essential materials and petrochemicals relied upon for building components and infrastructure construction, goods manufacturing, industrial transport systems, etc. This implies not wasting the opportunities during the post-peak oil plateau period, but taking adaptive action at government level with fully educated community support.

N. In the *adaptation phase* of oil depletion all new land development and buildings are potentially affected until replacement fuels/renewable power sources become available for substantial conversion of all diesel powered commercial/industrial transport, machinery and equipment. Such conversions apply to the whole chain of cradle-to-gate production of all building and engineering materials and components, as noted in Chapter 4. Well-analysed integrated transformation strategies for alternative 'fuels' and distribution systems are implemented in conjunction with alternative vehicle manufacturing programs. These programs will take a decade or more to develop and implement the technology to transport goods and move people within and to cities (Hirsch et al. 2007). Australia is adversely affected by the demise of the Ford and General Motors vehicle manufacturing capability that will occur as soon as 2017 in the early mitigation phase (Sydney Morning Herald online, 16 December 2013).

O. In the *constrained phase* of oil depletion, the movement of people, goods and materials requires complex reorganisation of resources under the guidance of governments beyond indicators L and M. Strategies implement renewable stationary energy and alternative automotive power technology away from reliance on oil- and gas-based solutions. The public transport system is fully developed during the adaptation phase and light rail and bus routes can be used to transport goods at night time to internal distribution points. Liquid and pneumatic pipelines can move continuous supplies of substances and containerised goods.

The modified sustainable urban form phenomenon narrative acts as a set of indicators, with which the future development of sustainable urban forms at the reference City of Gold Coast can be compared. The general indicators need to be verified as reasonable theoretical propositions. It is intended to do this by suggesting hypotheses for evaluation in response to research objective 3.2 in Chapter 7.

6.3.3 Evaluating oil-constrained sustainable urban form propositions

The constant comparative method of building the theories first generates *sustainable urban form* concepts grounded in the data and proposes theoretical propositions for evaluation as grounded theory hypotheses to see if they can be supported (Strauss & Corbin 1998: 33; Glaser 2004: 9; Gray 2009: 166). During the course of the GT research, the purpose is to establish the best fit of concepts to a set of indicators. New concepts or insights may also emerge as the research progresses, or be recognised as being more important than first assumed (Glaser 2004: 9). In this study, all the above indicators are interrelated—so are included in the set—but some have more direct relevance to the research problem, which focuses on urban residential form. Under these circumstances it is considered prudent to delimit the theoretical sampling and reduce the set to the most relevant indicator properties. Glaser suggests that such 'reduction occurs when the analyst discovers underlying uniformity in the original set of categories or their properties and then reformulates the theory with a smaller set of higher level concepts' (Glaser 2004: 10). This section advances that process by suggesting the following theoretical propositions and attaching to them the most relevant sustainable urban form concept indicators in section 6.3.2 as a matrix in **Table 6.7**:

1. The effects of oil constraints relating to sustainability of land development and building construction occur across the typology of urban residential forms;
2. The significance of oil constraints operates at various scales of the urban structural units and the relevant building-related energy flows;
3. The significance of oil constraints relates to urban expansion (suburban sprawl);
4. The influence of oil depletion on land use planning policies relates to sustainable urban residential forms (within the Australian urban context).

The theoretical sorting reduces the key concepts from 27 in section 6.3.1, to 15 in section 6.3.2, and to 12 in Table 6.7. The matrix reflects the clustering of planning (green) and energy related (blue) indicators from section 6.3.2 to aid in development of grounded theory hypotheses about the relationships that will be verified in Chapter 7

Table 6.7: Matrix of relevant indicators to sustainable urban residential forms

Theoretical propositions legend:

1: Effects of oil constraints across the typology of urban residential forms

2: Significance of oil constraints at scales of the urban structural units

3: Significance of oil constraints to urban expansion (sprawl)

4: Influence of oil depletion on land use planning policies

Relevant indicators in section 6.3.2:	Significant to propositions:			
	1	2	3	4
A: Well-defined urban planning boundaries to facilitate densification	♦		♦	♦
B: Low density residential development is limited by planning policies	♦		♦	♦
C: Activity centres are planned as mixed-use 3-dimensional development	♦	♦		♦
D: Urban design/planning for dense development	♦	♦		♦
E: Medium rise/high density apartment buildings a preferred type	♦	♦		♦
F: Multiple modes of P-AMOD with appropriate densification of urban form	♦	♦	♦	♦
G: Shared traffic-pedestrian low speed zones supporting active transport		♦		♦
H: Building codes support innovative design; energy-efficient buildings	♦			♦
I: Vernacular architecture in residential buildings; off-site manufacture	♦	♦		
J: Reduced urban ecological footprint; urban farming	♦		♦	♦
K: High rise residential towers embodied and operational energy issues	♦	♦		♦
L: Renewable energy sources become independent of the oil-economy	♦	♦		
O: Government guided integrated transformation strategies for renewable stationary energy and alternative transport energy sources and distribution systems (includes M and N)	♦		♦	♦

(Strauss & Corbin 1998: 191). The first proposition spans across both clusters. The second proposition focuses on the types of development at a precinct scale and the relevant building-related energy flows. The third proposition is significant to city-wide scale of development, broad P-AMOD strategic policy issues and energy sources. The fourth proposition confirms the influence of oil constraints on planning policies at both precinct and city-wide scales, including policies related to metabolic and transport energy flows. These theoretical considerations suggest modifying the theoretical propositions into *four grounded theory hypotheses*:

1. Oil constraints may affect the sustainability of land development and building construction across all types of urban residential forms.
2. Oil constraints may be significant at the precinct scale of the urban structural units to energy efficient urban design and building-related metabolic energy flows.
3. Oil constraints may be significant at the city-wide scale of urban expansion.
4. Oil depletion may influence land use planning policies (within the Australian urban context) at both precinct and city-wide scales, including planning policies related to metabolic (embodied and operational and transport) energy flows.

6.4 Conclusions on oil-constrained sustainable cities

This chapter has addressed objective 3.1 of research question 3 using grounded theory methods to investigate relevant qualities of sustainable cities and to suggest characteristics for oil-constrained cities, by drawing on values of pre-oil economy cities and the experience of modern cities within a wider context of sustainable urban design for residential development forms. The centres of old cities have survived the evolving socio-economic circumstances in essentially the same urban form. Observations of the physical qualities of these old cities suggest characteristics that may inform the grounded theory. Such cities are not static entities, but have embraced modern energy and transport technologies to match more modern cities studied in the research. However, the outward expansion of old cities has also resulted in problematic urban sprawl.

The open coding of the observations to show themes and relationships enables ranking of eight groups according to three scenarios, ranging from the historical precedence to a future with conditions of constrained petroleum supply. Categorisation of the open coding suggests the core variable is a combination of the Urban Structural Unit and the Urban Fabric Design groups that is expressed as *sustainable urban form*.

Axial coding of data in relation to those variables that relate to the core variable in significant ways articulates a smaller set of higher-level concepts. The coding elaborates the dimensions and properties that may explain the relationships in response to three questions in the context of the sample European and other cities. Comparison of the relevance of categories in selective coding of the eight groups amalgamates Tables 6.3–6.5 into a condensed set of 27 relationships in Table 6.6 that validate the *sustainable urban form* as the phenomenon of the study. A modification of the original definition of urban form in section 2.1.2 describes the properties of the core category in terms of the characteristics of an urban area as a set of complex relationships comprising:

a. the framework of urban structural units in a hierarchy of scales, transformed within the emerging historical, geographical, ecological and climatic context
b. the urban design— shape, height, density and appearance—of the built environment, including the interface between the built environment and public realm—streets and public spaces, public and private open greenspace
c. mobility and movement hierarchies—networks and transport systems
d. the urban metabolism supporting, facilitating and sustaining the socio-economic functionality of a city, including social and cultural processes, metabolic flows of substances, goods, energy and communication within a regenerative ecological footprint.

A schematic model of the completed coding process at Figure 6.11 suggests the relationships between the core variable and the sub-categories in the context of scenario C, in which the designated causal condition oil depletion could be modified by the properties and dimensions affecting the central phenomenon to produce an outcome analogous to an oil-constrained sustainable urban form. The modified phenomenon narrative suggests a set of indicators, with which the future development of sustainable urban forms at the reference case study City of Gold Coast can be compared. The indicators are validated as theoretical propositions by theoretical sorting to reduce the key concepts from 27 in section 6.3.1 to 12 as a matrix in Table 6.7. The matrix reflects the clustering of planning and energy related indicators from section 6.3.2 and assists the development of grounded theory hypotheses that will be evaluated and verified in Chapter 7. The theoretical considerations suggest the modification of the propositions into the following grounded theory hypotheses:

1. Oil constraints may affect the sustainability of land development and building construction across all types of urban residential forms.
2. Oil constraints may be significant at the precinct scale of the urban structural units to energy efficient urban design and building-related metabolic energy flows.
3. Oil constraints may be significant at the city-wide scale of urban expansion.
4. Oil depletion may influence land use planning policies within the Australian urban context at both precinct and city-wide scales, including planning policies related to metabolic (embodied and operational and transport) energy flows.

This chapter has pursued objective 3.1 of research question 3 to lay the foundation of grounded theory investigation into relevant qualities of sustainable cities and to suggest characteristics for oil-constrained cities. The hypotheses derived from the coding process form the starting point in Chapter 7 to address objective 3.2 of research question 3, which is to develop grounded theories about sustainable residential development in an oil-constrained future in the reference Australian City of Gold Coast; and how planning can contribute to a transformation of urban residential forms.

Chapter 7

Oil-constrained sustainable urban residential forms

A pessimist sees the difficulty in every opportunity;
an optimist sees the opportunity in every difficulty. (Winston Churchill: n.d.)

This chapter addresses research question 3.2 to develop grounded theories about sustainable residential development in an oil-constrained future within the Australian urban context of the City of Gold Coast. The Churchill quote is apt, because it is important to penetrate the gloom surrounding peak oil predictions and implications. The light cast by this research on the wicked global oil depletion problem, as it relates to urban residential development, is intended to be from a post-positivist, neutral viewpoint that is free of hindsight bias. Oil depletion creates opportunities for a more sustainable and resilient urban development pattern (Rubin 2009: 243), and benefits for climate mitigation. The Part 1 hypothesis adopts a neutral approach in establishing that:

> *Significant relationships exist between new urban residential development and oil supply constraints in the growth of major cities in the Australian context, with respect to land development, building construction and ancillary transport aspects that affect all stages of such processes; thereby requiring oil depletion adaptation strategies.*

The grounded theory method develops the systematically generated sustainable urban form concepts in Chapter 6 into grounded theories in this chapter in the following sequence:

> Sustainable urban form concepts → develop theoretical propositions → propose grounded theory hypotheses → evaluate/verify to support theoretical propositions → transform into grounded theories about the phenomenon – sustainable forms of cities with oil-constraints.

The grounded theories will inform refinement of an integrated conceptual framework that can be expressed abstractly from the Figure 6.11 key relationships as:

> P1 global oil supply depletion affects P2 sustainable forms of cities ⟶ P3 desirable outcome

An abductive approach (in accordance with section 3 of Appendix A) aims to evaluate and verify the grounded theory hypotheses by focused interviews with experts in the planning and development sectors. The interviews also assist in exploring how land use planning may contribute to an orderly transformation to an oil-constrained future, with application of the grounded theories to the City of Gold Coast in Chapter 8.

7.1 Development of grounded theories and models

This section develops the grounded theory propositions and hypotheses in Chapter 6 into grounded theories and models. The abductive method steps back from the coding to draw in the detailed insights of data gained from the material flow analysis (MFA) and the case studies as a check on the theory development (as suggested by Strauss & Corbin 1998: 85; and Gray 2009: 512). The analysis in sub-sections 7.1.1-7.1.4 aims to verify if the following grounded theory hypotheses derived in Chapter 6 are supported:

1. Oil constraints may affect the sustainability of land development and building construction across all types of urban residential forms;
2. Oil constraints may be significant at the precinct scale of the urban structural units to energy efficient urban design and building-related metabolic energy flows;
3. Oil constraints may be significant at the city-wide scale of urban expansion;
4. Oil depletion may influence land use planning policies (within the Australian urban context) at both precinct and city-wide scales, including planning policies related to metabolic (embodied and operational and transport) energy flows.

7.1.1 Hypothesis 1: effects of oil constraints on sustainability of new residential development

Land development, building materials and construction processes are central elements to this thesis for assessing the possible effects of oil constraints on urban residential forms in hypothesis 1. The embodied energy is the basis for evaluating the first two elements. Material flow analysis (MFA) demonstrates significant relationships between oil-related inputs and the urban built environment. The transport related factors of oil and gas inputs underlie all these elements. A qualitative interview method used in Chapter 5 and Appendices D–G assesses the construction process element.

The direct inputs of oil in land development are in the diesel power for all the plant and equipment used for land clearing and road construction, and as asphalt for road surfacing. The main non-transport indirect oil inputs are in petrochemicals (e.g. plastics and surface coatings, and rubber products). However, oil and gas also feature in the manufacture of most building materials listed in Table 3.3 either as embodied energy (heat) input, or as liquid fuels in the transport related inputs. Building materials include the key concrete, brick making, steel and timber products. While the thesis focuses on non-transport related issues of oil depletion, the MFA and case studies demonstrate that ancillary transport issues are critical factors and are integral to all material extraction, harvesting, processing, manufacturing and delivery to development sites for the construction of all building types. This is distinct from transport related to general mobility of the population and movement of non-construction goods and services.

Section 5.6.4 concludes that all the cases are dependent upon road transport and diesel powered machinery, related to materials, components and labour. Hence the deceptively small recorded transport embodied energy in each case is not the whole story in examining the possible impacts in an oil-constrained future. The road haulage of materials and goods is difficult to quantify accurately in the case studies, partly because of the diverse sources of material supply and the goods distribution networks from Brisbane and elsewhere to the Gold Coast (including nationally imported materials).

The vulnerability of all new land development and building construction to oil constraints affects all types of residential development to varying extents and therefore supports the hypothesis. The effects include the ancillary transport system until replacement fuels become available for diesel powered vehicles, plant and equipment.

7.1.2 Hypothesis 2: significance of oil constraints at precinct scale of urban structural units

Hypothesis 2 relates to how oil constraints may have significant effects—at just the building lot or at a wider precinct scale of the city form. While this research is morphological in describing the urban form, it essentially links to the transformative process of adaptive urban design, in terms of building types, density, structure and energy flows. Section 2.1.2 points out that a poor or inefficient urban design outcome could also be maladaptive in an oil-constrained future.

The characteristics of cities with an oil-constrained sustainable urban form (section 6.3.2) suggest that efficient urban design and planning for dense development features small block sizes, semi-continuous street façades, with active frontages and green street design with a hierarchy of road widths in a network of landscaped plazas. These features are facilitated by medium rise/high density apartment buildings as the preferred type of residential development, compared with low density detached housing and high towers (unless above a podium). One pilot case study inference in section 5.6.1 confirms that the differential effect of embodied energy at the individual building scale is least for a medium rise (six storey) apartment building measured as intensity per m^2, on the basis of assessed materials and processes. The differential land requirement based on building footprint also favours greater density residential development. The semi-continuous façade of perimeter blocks is closely associated with medium rise/high density apartment buildings. Hence the impact of oil constraints on construction primarily affects urban design at the block scale—extending to the precinct and possibly to neighbourhood scales. This is reflected in the urban morphology based on an urban structural unit (USU) framework (Osmond 2010: 18), which includes the materials and energy flows that characterise urban form.

It is considered that the archival data in Chapters 2 and 6 and the reported case studies in Chapter 5 support the provisional explanatory hypothesis. Further verification is explored in focused interviews with experts in the planning and development sectors.

7.1.3 Hypothesis 3: significance of oil constraints at city-wide scale of urban expansion

Hypothesis 3 relates to how oil constraints may be significant at the city-wide scale of urban expansion (particularly described as suburban sprawl). Section 2.1 demonstrates that cheap oil has facilitated suburban sprawl. The cottage (detached dwelling) form of housing dominates the Australian suburban form and there is little doubt that from solely a building perspective, it could continue indefinitely, given sufficient greenfield land and engineering services. However, land development and house construction methods—including transportation of materials and components—based on the oil economy are vulnerable to change, as noted in hypothesis 1. They could revert to local alternative materials, but are also considered likely to take advantage of technological solutions such as off-site manufacture. The suburban urban form is subject to much debate in Australia, including recent studies such as *Transforming Australian Cities* (Adams 2009) and *Greening the Greyfields* (Newton et al. 2012), both of which advocate for redevelopment of middle suburban precincts at higher densities. This is despite the evidence indicating that 'much infill housing remains car-dependent' in greyfield infill, even with good public transport access (Newton et al. 2012: 147).

A negative issue pertaining to suburban living is personal transport operating cost and future fuel/powerplant uncertainty (Aftabuzzaman & Mazloumi 2011: 698). The oil depletion mitigation phase impacts will exacerbate mobility issues of outer suburbs and further distort the economics of housing, as demonstrated in the VAMPIRE model (Dodson & Sipe 2007), even with improving affordability if suburban house values fall over time. During the adaptation phase, the impact will extend to middle suburban areas not supported by convenient public transport, and will affect all cross-city mobility. Resilience planning of existing suburbs would transform most of the city towards an integrated public-active mobility oriented development (P-AMOD) focus. The P-AMOD model extends the 400-800m TOD nodal focus to a one kilometre/15 minute walking radius and increases density across the urban precinct. This radius aligns with the *Connecting SEQ 2031* '15-minute walkable neighbourhood' (Queensland 2011: 30) reviewed in Appendix H. Section 4.2.4 distinguishes P-AMOD precincts from TOD nodes and corridors by focusing on mobility within the larger precinct. Flexible public transport operates without the pressure for park-and-ride parking facilities, because the population density supports more local employment and urban amenities in mixed use form-based zones.

A minority of researchers assert the positive aspects of suburban living to the extent that city lifestyles may even be saved by suburbs (Lewis 1999, Troy 2003) and that suburbs offer significant opportunities for urban agriculture (Adams 2009; Weller et al. 2009). This concept supports the related characteristic of a sustainable city in section 6.3.2 (B) that suggests the outer suburban segments of the urban transect are gradually transformed into a productive urban living/horticulture zone. Section 6.2.2 estimates the food footprint of the Gold Coast city at 800,000 population as being 12,000 km^2 (10 times the city land area—equivalent to area of Northern Ireland).

The vulnerability to oil depletion is significant and will inhibit suburban sprawl to increase redevelopment of inner urban serviced areas; unless mitigated by complete replacement of fuels for diesel powered vehicles and machinery. A social barrier to infill redevelopment is the resistance of existing inner city residents to medium and high rise projects. This trend also results in rising property values that make many such projects unaffordable to low and modest income residents. Transport system-wide replacement fuels and vehicles (e.g. hybrid gas/electric) may facilitate resettlement of existing outer suburbs by families desiring a suburban lifestyle.

It is considered that the archival data in Chapters 2 and 6 and the reported case studies in Chapter 5 support the provisional explanatory hypothesis. Further verification is explored in focused interviews with experts in the planning and development sectors.

7.1.4 Hypothesis 4: influence of oil depletion on land use planning policies

Hypothesis 4 relates to how oil constraints may influence land use planning policies in the Australian context, as one of a number of drivers contributing to urban residential form at both precinct and city-wide scales, including policies related to metabolic and transport energy flows. A transformative (yet not necessarily sustainable) role of land use planning is at the heart of most theories as they have evolved from the garden city concept of Ebenezer Howard through modernism and new urbanism to transit oriented development and other planning concepts. However, effective implementation relies on private enterprise in the Australian property and building sector context. At the site scale, housing types and construction form are largely dictated by the investment market and lending institution policies that act as development drivers, in addition to planning and other policies—as indicated in the planning framework at Figure 4.9.

The case studies in chapter 2 overview the current planning strategies for urban growth management in three representative major Australian cities. Yet as of 2014, no metropolitan planning strategy had taken into consideration the implications of oil depletion, beyond a broad reference to future oil vulnerability, or rising petrol prices.[25] However, section 3.1.2 of Chapter 3 demonstrates that an oil depletion scenario is relevant to the current 20 year spatial planning strategic horizon, as acknowledged in the City of Stirling Oil Risk Strategy, the Maribyrnong Oil Contingency Plan and the Sunshine Coast Regional Council Climate Change and Peak Oil Strategy 2010-2020.

Section 4.3 highlights the ongoing planning reforms underway in Queensland and how they may affect the moderating regulatory and planning factors in the initial conceptual framework. Currently there is no vision for regenerative cities. Development of a future sustainable urban environment, required by the SPP (DSDIP 2013b: 16) and implied in the regional planning, may become contingent on the adaptive strategies for oil depletion, including the construction of the built environment and the evolving urban form. Such guidance is unlikely in current SEQ Regional Plan proposals. One policy catalyst will be international acceptance—e.g. by the IEA and EIA—of oil depletion as a wicked global problem. The conclusion is that this hiatus in the Queensland policy

25 The Gold Coast *City Plan* planning scheme adopted in February 2016 reflects the economic development priorities and policy directions to develop into a world-class city. The Strategic Framework signals a major shift in direction away from outward expansion towards redevelopment of urban centres and key inner-city neighbourhoods to achieve 'an orderly and economically efficient settlement pattern' (GCCC 2016: Part 3 p.3). While the planning principles include renewal and transformation in places such as the Southport CBD noted in section 4.3.3 of Chapter 4, there is no mention of oil depletion or even oil vulnerability within the designated planning horizon to 2031.

setting agenda is an opportunity to raise oil depletion as a relevant planning issue. It is considered that the planning context in Chapter 2, and the planning system reforms outlined in section 4.3 support the provisional explanatory hypothesis to the extent that oil constraints *should* influence land use planning policies.

The initial verification of the four hypotheses leads to the next section in proposing grounded theories and models that explain the core category of the phenomenon. This is determined to be a *sustainable urban form* and the desired outcome is an oil-constrained sustainable urban form. The grounded theories are further verified by focused interviews with experts in planning and development in section 7.2.

7.1.5 Four grounded theories and models for oil-constrained cities

Grounded theories 'explain some relevant phenomenon through statements of relationship between two or more concepts and the consequences' (Strauss & Corbin 1998: 22). The theories and models developed from the four verified hypotheses may offer insight, enhance understanding, and provide a meaningful guide to planning-related action on oil depletion. Such direction is necessarily qualified by a range of factors beyond the scope of this research as discussed in Chapters 2, 3 and 4. Coincidentally the theoretical concepts progress in the morphological scale of urban structural units from lot to precinct to city-wide to metropolitan region and beyond.

Theory 1: effects of oil constraints on sustainability of all new development

The following theoretical concept is developed from analysis of the provisional explanatory hypothesis 1 derived in Chapter 6:

> *Oil supply constraints will gradually affect the sustainability of all new land development and construction of all types of urban residential buildings to varying extents, depending on the materials used and transport-related factors. Materials-related vulnerability may be reduced by adaptation to non-petroleum substitutes. Transport-related vulnerability may be reduced by conversion of diesel powered construction vehicles and machinery to available replacement 'fuels' as a mitigation strategy in the short–medium transitional phase.*

This theoretical concept is supported by the insights gained through MFA and pilot case study empirical data, which demonstrate the vulnerability to oil constraints of all material extraction, harvesting, processing, manufacturing, distribution and delivery to development sites. The effects of oil constraints will increase as global demand exceeds supply, but may be mitigated by the substitution of local non-petroleum based materials.

Transport is an essential ancillary factor that is integral to dwelling construction processes in all urban forms. Greenfield land development is most dependent upon oil energy; commercial scale infill development is potentially slightly less so. The scaling up process of adaptation to replacement 'fuels'—including gas, biofuels and electric power for vehicles—is problematic as it is largely market driven. The process requires a balance of vehicle and machinery conversion matched by alternative fuel distribution networks. Biodiesel is the easy solution, but is considered only an interim alternative.

Theory 2: significance of oil constraints at precinct scale (urban structural units)

The following theoretical concept is developed from analysis of the provisional explanatory hypothesis 2 derived in Chapter 6:

> *Adaptive design for oil-constrained sustainable urban residential forms at the precinct scale of urban structural units is facilitated most efficiently by medium rise/high density apartment buildings arranged as perimeter/courtyard blocks, in terms of achieving objectives for building material and energy flows, urban density, adaptable functionality, streetscape and public-active mobility oriented development.*

This theoretical concept is supported by the insights gained through a pilot cross-case comparison of the building typology summarised in Figures 5.16 and 5.17 of Chapter 5. The differential effect of oil inputs operates at the individual building lot scale; is least for a six storey apartment building case and most for a high rise tower case. Embodied energy intensity per square metre of building area is measured on the basis of assessed currently predominant materials and processes within the Australian context. The characteristics of sustainable cities in Chapter 6 suggest that efficient urban design for dense development features small block sizes, semi-continuous street façades, with active frontages and green street design in a network of landscaped plazas. These features are facilitated by medium rise/high density apartment buildings as the preferred type of urban residential development having lower embodied energy.

Theory 3: significance of oil constraints at city-wide scale (urban expansion)

The following theoretical concept is developed from analysis of the provisional explanatory hypothesis 3 derived in Chapter 6:

> *The transport-related mitigation phase of oil depletion will increasingly inhibit suburban sprawl led city-wide expansion and accelerate redevelopment pressure in inner urban serviced areas close to public transport. In the later adaptive phase, availability of system-wide alternative energy powered vehicles may mitigate mobility and living cost issues in more affordable housing in existing middle/outer suburbs.*

This theoretical concept suggests that while the detached dwelling form of housing could continue indefinitely given sufficient greenfield land and engineering services, impending oil depletion will accelerate a socio-economic pull factor to redevelopment pressure in inner city urban areas. The benefits of better mobility and public transport, as well as greater density of urban amenities and facilities, outweigh the housing costs. Infill development is an important planning policy for more sustainable urban forms, but faces resident resistance to medium and high rise projects. This policy also results in rising property values that make many market driven projects unaffordable to low and modest income residents without subsidy. These counter pressures act as barriers to densifying inner city areas under normal market forces; becoming a push factor back to lower cost middle-outer suburbs, needing to be facilitated by increasing availability of system-wide replacement fuels and vehicles for families wanting more private land.

Theory 4: influence of oil depletion on land use planning policies

The following theoretical concept is developed from analysis of the provisional explanatory hypothesis 4 derived in Chapter 6:

> *As the phenomenon of oil depletion gains international acceptance as a wicked global problem, it will influence government urban land use policies at both city-wide and regional scales within the State and Australian planning system context. Transformative guidance on urban metabolic energy flows is linked to state and national policies on transport, renewable energy and climate change mitigation.*

Currently proposed strategic planning tools in the Queensland context have a potential negative influence on the desirable forms of urban development, because there is no guidance in the new State Planning Policy on mitigation of, or adaptation to, future oil depletion and constraints, or on climate change. International acceptance of oil depletion as a wicked global problem would be a policy catalyst to influence national and state action, including the proposed Queensland planning legislation and the State Planning Policy strategic guidance. Transformative guidance on urban metabolic energy flows should be linked to state and national policies on transport, renewable energy and climate change mitigation for incorporation into revised planning schemes.

The effective implementation of planning policies relies on private enterprise in the property and building sectors in the Australian context. At the site scale, housing types and construction form are largely dictated by the investment market and lending institution policies that act as development drivers, and need clear guidance by planning policies for future oil-constrained sustainable development. The future changes in the oil economy will also presage changes in the banking and property investment domain. These predicted crises could facilitate a transformation in land tenure and housing finance to what may be termed assisted or managed capitalism (e.g. Wallerstein 2000, Diamond 2005, Heinberg 2011). This is a field suggested for further research.

7.2 Focused interviews to verify grounded theory concepts

Focused interviews with six experts in the fields of land development, planning, architecture and transport elicited views to further verify the development of grounded theories and the summary suburban development model. The interviews were conducted in accordance with the Bond University ethics clearance RO-1061 conditions prior to the release of the Queensland State Planning Policy and planning reform proposals. This section records and analyses the discussion generated by six sequenced themes related to the grounded theory coding and theoretical concepts above:

1. awareness of peak oil studies and what it may mean in the future (current strategic planning horizon of 20 years) to urban planning in general terms (brief overview)
2. awareness of possible oil depletion planning implications beyond transport impacts on urban forms
3. An overview of the land development and building construction vulnerability issues raised by the case study material flow analysis results
4. focussed discussion on the types of urban residential development forms that may require major adaptation strategies to remain viable in an oil-constrained scenario
5. ways that the current planning system can hinder or facilitate more viable urban residential forms
6. alignment with current urban planning theory and best practice directions for transformation towards sustainable urban development.

The expert interviewees were selected on the basis of their wide ranging expertise in policy and practice at senior levels in state and local government planning agencies; or in architectural and planning consultancies. The ethics clearance RO-1061 by Bond University is subject to maintaining their anonymity in the thesis. However, their identities and transcripts of the one hour recorded interviews are kept securely at the university for future reference. Four interviewees have experience in both private and public practice at senior executive level. One of those planning interviewees is also a member of the Association for the Study of Peak Oil and Gas (ASPO). Another interviewee is a multi-award winning architect with over 30 years' experience and is a director of a national architectural practice.

The focused interview approach was selected because it allowed for non-directive discussion to explore a limited number of semi-structured topics, based on personal knowledge of the interviewees' experience over many years (Gray 2009: 373). This was intentionally in accordance with section 3.2 of the Research Methods Appendix A. Each interviewee was given a summary of the thesis conceptual framework, general research design, case study findings summary table and graphs, with six questions as the basis for discussion. The discussion was open ended in each theme and some variation therefore occurred in the consistency of the verbal responses. The small number of individual responses made computerised thematic analysis unsuitable. Hence the discussions were analysed manually and are presented below.

7.2.1 Theme 1: peak oil awareness

The general awareness about peak oil by five of the interviewees indicated a similar level to other planners interviewed during this research (as recorded in sections 2.2.2, 2.3.1 and 6.2), ranging from a low technical awareness to a general working knowledge. Low awareness of the implications beyond the climate change mitigation issues was therefore expected. One typical response was that we are smart enough to find technological solutions to the technical problems. In contrast, excellent awareness shown in the ASPO member's responses was as expected, because of his many years' experience researching oil issues. He noted a reporting bias in the media about unconventional oil, which assists in denying that there is a peak oil issue.

7.2.2 Theme 2: consideration of oil depletion planning implications

There was general acknowledgment of a disconnection between awareness of peak oil and any commitment or action to a change in planning. Even though some councils have developed policies on oil vulnerability and climate change, it has had minimal impact on their plan making and decision making. Interviewees reported strong resistance by the development industry in South East Queensland to change traditional modes of operation. Although planning policies such as transit oriented development (TOD), mixed use and higher densities aligned with energy responses, it was easier for developers to get approvals for traditional land subdivision and detached housing products. This reinforced the difficulties in effectively implementing major shifts in policy—including a perception problem of proving that the changes are needed—similar to resistance by climate sceptics to implementing effective climate change planning responses.

However, climate change responses could be seen as a current planning fad that tends to have a single issue focus. Transport planning has evolved in recent studies such as Connecting SEQ 2031 (Queensland 2010a), but it has a heavy emphasis on road development. One interviewee argued that all manufacture, commerce and distribution depend on oil-powered vehicles. This is a business as usual approach that ignores future oil constraints. Only two interviewees commented that other issues beyond transport are equally important, such as home heating that relies on oil and gas in cold climates (not so relevant to the subtropical City of Gold Coast).

7.2.3 Theme 3: land and building vulnerability issues

The architect made most comments about the case study findings on embodied energy. The comments aligned with the results for the case C six storey building being most efficient and extended to the economies beyond the embodied energy, to savings in fire services and effective operational energy savings in the building shape and layout:

> A commonly held opinion in the industry is that a six storey scale of building is economical scale to build. That is not particularly because of embodied energy, but because of the time per occupant to build the building is relatively low. Typically a six storey building will have only one basement, or maybe none; whereas a taller building will have at least one and probably two [noting that the 30 storey case has three basement levels]. Those basements require a significant amount of retaining walls and effort to keep out groundwater, whereas a six storey building tends to enable a much earlier start on building the tower superstructure.
>
> These buildings are therefore very quick to build and quite economical generally on the sites they occupy. There are a number of other features about them that are

> not required, such as the high level of fire services, sprinkler systems, dual stairwells and stair pressurisation, or other fire devices that are used in multi-storey high rise buildings. So that in itself leads to a more efficient floor plate and cuts $50 to $100 per m^2 off the building cost. It would also reduce some oil and gas inputs.
>
> This style of development [six storey building] is designed to give cross-ventilation to the apartments and maximise the amount of external wall that is available for bedrooms and living rooms. … Although there is probably a small increase of common area in the six storey building case example, the positive trade-off is substantial. (Architect interview, 10 May 2013)

One response about vulnerability was to acknowledge that the trend to larger houses is slowly reversing, but was considered to be driven more by land and construction costs than by energy considerations. A related response about vulnerability was to agree that extractive resources and cement are highly dependent on oil for production and delivery. Hence these materials will become more expensive and more difficult to acquire in the future, partly because of greater haulage effort. Moreover, the trend to local and lightweight materials will increase for similar reasons, as well as an increase in suspended timber floors.

A suggestion to improve the results of the case studies is to expand the boundary conditions by including more of the land clearing and provision of engineering services to the site in a typical location. This applies mainly to greenfield development, which is only relevant to the case A detached house. The other cases, with the taller buildings, are increasingly likely to be infill development. The effect on the cases would be to increase embodied energy of the low density house closer to the six storey building. More generally, resident resistance to high rise buildings would point to the efficacy of corridor redevelopment as a preferred option for future densification of cities.

7.2.4 Theme 4: urban residential development forms

The cost of land and housing is acknowledged to be a major issue in planning cities. The changing demography is not yet reflected in the type and design of houses except in inner city locations. The older generation of planners and architects is not generally cognisant of these paradigm shifts. Tiny lots (less than 100 m^2) and innovative housing in overseas (European, Asian and African) cities are not seen as being equally relevant to the Australian culture (even though migrants from such cities are used to them).

Generally the community has a greater interest in purchasing a stand-alone, detached dwelling in the suburbs, even subject to all sorts of associated issues, than in purchasing an alternative housing product adjacent to say a railway station, even when they are very similar prices. People are likely to go for the traditional product rather than the more adaptable urban form product. So there are two barriers to translating policy into a new urban form outcome: the developers can’t afford to build the new outcome for the market at this point; and the community is not particularly interested in purchasing the new outcome. Leasehold is an alternative, as in Brisbane’s South area

(South Bank Corporation Act 1989: 59). The planning initiatives relevant to this research are to promote mixed use and higher densities, co-location of different activities on the one parcel of land integrated with residential development and transport and other infrastructure. They are particularly effective where they can be actually demonstrated in modern new housing developments (e.g. smaller dwellings) as being worthwhile doing and promoting, such as the Urban Land Development Authority (2012) project at Fitzgibbon Chase in Brisbane.

However, two interviewees consider that the behaviour of the people living in even an award winning modern residential development with desirable mixed use and lifestyle attributes is not likely to be very different in travel behaviour to people in more traditional sites. So this in itself is a barrier to change. Although the urban form may assist people to change their behaviour if they need to in the future, it is untested and unproven. The interviewees considered that no convincing evidence has been offered that suggests the alternative or new urbanism communities lead to a substantial increase in the use of public transport, or lead to a stronger resilience on behalf of the people, compared to a more conventional suburban community. The biggest differences are usually found in comparing new estates to established areas.

The interviewees are all in general agreement about the value of urban village style development being desirable, regardless of any oil depletion issues (e.g. Barton 2000).

7.2.5 Theme 5: current planning system barriers and facilitation

Current planning systems and codes act as barriers, because the thinking behind a lot of the current planning codes is based in the 1970s, '80s and '90s, i.e. in the past. The codes centre on the demography of household types that were in existence over 20 years ago—the majority were couples with children or couples that intended to have children. Now couples without children are overtaking couples with children and are probably not going to have any children, so their household choices are going to be different, particularly when costs are very high (Queensland Treasury and Trade 2012). Hence planning codes have to change to suit. Although these issues are not directly related to oil depletion, they are relevant to adapting to an oil constrained future.

One comment was that councils plan for the largest lot size demand, or consider that their area 'is different' to other cities. Master planning of communities is directed towards an end 'utopian' state and is not adaptable to incremental changes in density standards. The interviewee suggested that a gradual approach to densification would be preferable to mandatory infill policies. Facilitating rear lot infill would enable a significant increase in density and retain existing small scale residential character.

7.2.6 Theme 6: planning theory and best practice directions

One comment about the Brisbane context that is relevant to the Gold Coast future is Transit Oriented Development around rail stations. A recent unpublished state government study of supply within 400m of Brisbane rail station sites shows that sufficient potential exists for mixed use TOD to meet housing demand for 30 years. Secondly, all the people who are disposed to live in that type of accommodation, provided it is available at a competitive price, amount to only a small portion of the existing market. Most people are looking for a more traditional house, regardless of whether they are living next to a railway station. Strategically the key locations within the metropolitan area where high density mixed uses can be achieved are thus the ones to promote. This view is supported by other interviewees.

Southport is quite a large central business district and arguably larger in land area than the Gold Coast can support. There are some key sites that have become available for redevelopment such as the former hospital site, which could themselves house thousands of people. So Southport has excellent potential for redevelopment with the completion of the first stage of the light rail project[26].

A relevant comment about change management is that we need to create a constituency for a major (e.g. climate change) policy shift or it will not be respected. For example there are good planning reasons why we have growth boundaries. In South East Queensland the planning reasons for the introduction of new growth boundaries are the preservation of green space. This is also relevant to urban farming. That objective has strong community support and has led to a relatively strong application of a growth boundary to the urban footprint.

7.2.7 Social issues of acceptance to change

In addition to considering the physical, environmental and economic impacts of oil constraints on the built environment, there is also the social question of community acceptance of changes to urban form. A key issue for town planners invovled in turning policy into results that affect urban form is needing to influence measures that control people's behaviour. It is not enough to make the case for why a different urban form is more desirable, even if that is considered by planners to be important. It actually needs to be constructed, or implemented in a way that allows the different players—consumers of the final product, the developers, infrastructure and service providers—to actually want to do it.

This social issue has been raised by many commentators, including Michael Breheny (1996: 14), who suggests that 'in the debate about the role of planning in promoting sustainable development, the scope can be usefully summarised by classifying stances initially into two groups'. The decentrists 'favour urban decentralisation, largely as a reaction to the problems of the industrial cities'. The centrists 'believe in the virtues of high density cities and decry urban sprawl' (Breheny 1996: 14). However, a compromise middle course is considered to be more desirable as an effective planning strategy (e.g. Adams 2009, Newman et al. 2009, Newton et al. 2012).

[26] Implementation of the Southport Priority Development Area plan shown in Figure 4.13 confirms the catalytic effect of the light rail project shown in Figure 2.13B for high density urban renewal.

A common view is that people are conservative and will only make a change in their living arrangements on the basis that they've weighed up the advantages and disadvantages and have made that a personal commitment, which could be quite price elastic. People will pay a lot more to maintain a certain lifestyle, not determined by the cost of petrol and operating a car, but by what it means for them to have those choices. So given that buying a house and living in a particular way are really bound up in people's values, it is not surprising that people do not change very quickly in response to proposed or actual variations in urban form. Hence introduction of any moratorium on some types of development would be ineffective unless the government actually has built a similar constituency, firstly in the community and then definitely with key players in urban development. That includes the development community, regulatory and local authorities and councils, and servicing authorities. Unless there is strong support from most of those, a moratorium could not be achieved. The key to such a move is considered to be a popular issue like affordability. If the industry is not well placed to build alternative housing products such as TOD developments at a reasonable price, then a moratorium would also be ineffective.

Corridor oriented development—comprising TODs, new urbanism/smart growth neighbourhoods and urban villages—is promoted as a decentralised concentration approach. This approach may be supported by the Save Our Suburbs movement, which strongly advocates avoiding any extensive renewal of the leafy Melbourne suburbs, as noted in section 2.3.2; aiming for 'preservation of the bulk of the existing suburban area' (Lewis 1999: 265). The contribution by Patrick Troy (Jenks et al. 1996: 342) promoting the Australian suburban model is also argued in that study as being an appropriate low density urban form, offering higher quality of life, but it is heavily dependent on a modal/technological shift to more sustainable transport. Jenks et al. conclude that compact urban form must be not only a theoretical model, but also practically achievable: there is 'still considerable scope for further research to continue the search for a sustainable urban form and to find solutions to many of the problems' that are raised in the review (Jenks et al. 1996: 345). Clearly a sustainable urban form is a highly contested notion, regardless of potential future oil constraints.

A peer reviewed paper in the Australian Planner by Woodcock et al. (2012: 65-78) on envisioning the compact city reports on phenomenological research by the authors related to the centrist viewpoint, which is relevant to this thesis. The attitudinal survey tested the reactions to various scenario streetscape images by 46 Melbourne residents to 'a range of intensified city streetscape developments' in inner and middle suburbs. A key finding of the height and bulk scenarios was that 'the degree of non-acceptance increased significantly as buildings exceeded four storeys and setbacks decreased to zero'—evidence of the negative view of the streetscape canyon effect. The most acceptable level of intensification in the inner city area was for only four storey development set back 7 metres above the second storey behind mainly two storey historic commercial facades (six total storeys). An overall take-up of 60 per cent in such redevelopment was acceptable to 80 per cent of respondents.

However, in the developed visual imagery for an inner city scenario, the presence of mature street trees was a significant positive factor in increasing acceptability of more intensive development up to six storeys without any setback by an average of 41 per cent of respondents. It was considered to 'soften the heights of the new buildings' and enhanced the amenity value of the streetscape beyond the decorative and shade aspects (Woodcock et al. 2012: 72-73). Concern was expressed by some respondents about what was seen to be a seductive and cynical marketing exercise, as the expected trees may not be planted or not grow to indicated heights of 20m to screen six storeys. Two before-after inner city images are shown in **Figure 7.1** (Woodcock et al. 2012: 69).

Figure 7.1: Detailed urban design study streetscape visions

Source: Woodcock et al. (2012: 69) based on images provided by City of Melbourne

Top: Johnston St, Abbotsford (inner city) six storey vision. Acceptable to 63% (29 out of 46) of interviewees, 57% of middle suburbs interviewees, 68% of inner suburbs interviewees.

Bottom: Nicholson St, Brunswick (inner city) six storey vision. Acceptable to 41% (19 out of 46) of interviewees, 43% of middle suburbs interviewees, 40% of inner suburbs interviewees.

Such six storey medium rise redevelopment along active transit route corridors, with densities of 160 dwelling units per ha, is consistent with the intent of the *Melbourne 2030 Strategy* (Department of Infrastructure (Vic) 2002; Adams 2009). Yet it clearly relies on the realisation of an attractive streetscape to gain the community acceptance that occurs in the European model. It is also related to the 'green street' concept that better integrates the building-streetscape interface. The significant issue not tested, but implied in the case study, is that high rise buildings embedded in the streetscape even in an inner city location would generally not be an acceptable urban design solution, unless set back above a podium. Moreover, the case study area of Melbourne is nineteenth-century strip development with a continuous façade, which would have contributed to the social acceptance—a quite different scenario to a twentieth-century city such as the Gold Coast. Clearly it is not possible or even practicable for every street to have activated commercial and retail frontages echoing the old European cities, or the Melbourne strip type development decried by 1980s Australian urban planners on traffic and parking grounds. However, the general acceptance of buildings up to about six storeys does reflect the urban form of central Paris and many similar European cities, built in the pre-oil economy era.

7.3 Grounded theories and integrated conceptual framework

The value of the expert interviews in section 7.2 is in using another triangulation technique to verify, modify, or negate any of the proposed grounded theories. This section relates the interviews to the theoretical concepts proposed in section 7.1.5 in order to derive grounded theories and develop an integrated conceptual framework.

7.3.1 Verification of grounded theories

Theoretical concept 1

> *Oil supply constraints will gradually affect the sustainability of all new land development and construction of all types of urban residential buildings to varying extents, depending on the materials used and the transport-related factors. Materials-related vulnerability may be reduced by adaptation to non-petroleum substitutes. Transport-related vulnerability may be reduced by conversion of diesel powered construction vehicles and machinery to available replacement 'fuels' as a mitigation strategy in the short–medium transitional phase.*

Specific comments verified this concept by acknowledging that all manufacture, commerce and distribution depend on oil-powered vehicles. The interviewees somewhat supported the differential effects of oil constraints and suggested including more of the land clearing and engineering services to further differentiate building types from greenfield detached housing. An optimistic view suggested technological solutions will be found to the technical transport problems. There was no discussion in the interviews that would suggest modification of this theoretical concept.

Theoretical concept 2

> *Adaptive design for oil-constrained sustainable urban residential forms at the precinct scale of urban structural units is facilitated most efficiently by medium rise/high density apartment buildings arranged as perimeter/courtyard blocks; in*

relation to achieving objectives for building material and energy flows, urban density, adaptable functionality, streetscape and public-active mobility oriented development.

The architectural comments about the case study findings on embodied energy aligned with the results of case study C for the six storey building as being most efficient. The comments extended to economies beyond embodied energy to effective operational energy savings in the building shape and layout, superior natural ventilation for a sub-tropical climate, and cost savings in fire service requirements. Most interview discussion focused on the residential development forms. The planners generally supported the concept of compact development with active street frontages, but recognised the conservative preference for the traditional detached housing product rather than the more adaptable higher density apartment building product. Inner city resident resistance to high rise buildings would point to the efficacy of corridor redevelopment as a preferred option for future densification of cities. The planning initiatives in this research to promote mixed uses at higher densities, co-location of residential development with other infrastructure, and transport integration are likely to be more effective where they can be practically demonstrated in new such developments as being worthwhile and promoting sustainable outcomes. There was no discussion in the interviews that would require modification of this theoretical concept, except to be aware that even sub-optimal design at the precinct scale of urban structural units could achieve significant improvements.

Theoretical concept 3

The transport-related mitigation phase of oil depletion will increasingly inhibit suburban sprawl-led city-wide expansion and accelerate redevelopment pressure in inner urban serviced areas close to public transport. In the later adaptive phase, availability of system-wide alternative energy powered vehicles may mitigate mobility and living cost issues in more affordable housing in existing middle/outer suburbs.

A common view is that people are conservative and will only make a change in their living arrangements on the basis that the advantages outweigh disadvantages, which could be quite price elastic. People will pay a lot more to maintain a certain (suburban) lifestyle, not determined by the cost of petrol and operating a car. One interviewee suggested that a gradual approach to densification would be preferable to mandatory infill policies and retain existing small scale residential character. Corridor redevelopment is one such option. None of the comments negated the theoretical concept or the model for suburban transformation.

However, the wider social planning implications of infill development suggest that theoretical concept 4 on planning policies could be supplemented with an addendum to the effect that:

Detailed implementation of inner urban redevelopment to promote mixed use at higher densities would be subject to planning provisions to suit local conditions, including strategic guidance in oil depletion adaptation policies.

Theoretical concept 4

> *As the phenomenon of oil depletion gains international acceptance as a wicked global problem, it will influence government urban land use policies at both city-wide and regional scales within the State and Australian planning system context. Transformative guidance on urban metabolic energy flows is linked to state and national policies on transport, renewable energy and climate change mitigation.*

Current planning systems and codes act as barriers, because the thinking behind much of the current planning codes is based on an outdated demographic context. Current planning reforms could have a dual purpose of updating development with the paradigm shifts necessary to address demographic trends, as well as oil depletion and climate change adaptation. The interview comments in sections 7.2.5 and 7.2.6 and the study reported in section 7.2.7 are relevant to any strategic guidance in creating a broad constituency for major changes in planning policy directions for oil supply depletion adaptation strategies.

The possible introduction of mandatory codes for development control could not be supported in the short to intermediate term, until the extent of oil constraints is firmly established in the mitigation phase—i.e. as oil depletion gains international acceptance as a wicked global problem. Full public consultation and community engagement would be an integral component in developing any strategic guidance. The need for oil depletion adaptation was not disputed by the interviewees; however the linkage to climate change policies was not discussed in any detail.

None of the comments negated the theoretical concept; however, the implications of mandatory codes for control of infill development suggest theoretical concept 4 could be supplemented with the addendum noted above under theoretical concept 3.

Verified grounded theories

Verification of the grounded theoretical concepts and the summary model results in the following four grounded theories being proposed to explain the effects that possible future oil constraints may have on urban residential development, and hence their relationship to the planning of urban forms in the context of a twentieth century Australian coastal city. The theories are applied in section 7.3 to refine the conceptual framework.

1. *Oil supply constraints will gradually affect the sustainability of all new land development and construction of all types of urban residential buildings to varying extents, depending on the materials used and transport-related factors. Materials-related vulnerability may be reduced by adaptation to non-petroleum substitutes. Transport-related vulnerability may be reduced by conversion of diesel powered construction vehicles and machinery to available replacement 'fuels' as a mitigation strategy in the short–medium transitional phase.*

2. *Adaptive design for oil-constrained sustainable urban residential forms at the precinct scale of urban structural units is facilitated most efficiently by medium rise/high density apartment buildings arranged as perimeter/courtyard blocks; in relation to achieving objectives for building material and energy flows, urban density, adaptable functionality, streetscape and public-active mobility oriented development.*

3. *The transport-related mitigation phase of oil depletion will increasingly inhibit suburban sprawl-led city-wide expansion and accelerate redevelopment pressure in inner urban serviced areas close to public transport. In the later adaptive phase, availability of system-wide alternative energy powered vehicles may mitigate mobility and living cost issues in more affordable housing in existing middle/outer suburbs.*

4. *As the phenomenon of oil depletion gains international acceptance as a wicked global problem, it will influence government urban land use policies at both city-wide and regional scales within the State and Australian planning system context. Transformative guidance on urban metabolic energy flows is linked to state and national policies on transport, renewable energy and climate change mitigation.*

   Detailed implementation of inner urban redevelopment to promote mixed use at higher densities would be subject to planning provisions to suit local conditions, including strategic guidance in oil depletion adaptation policies.

7.3.2 Integrated conceptual framework

The focused interview method has verified four grounded theories for post-peak oil adaptation strategies. The grounded theories form the basis to refine the initial conceptual framework at Figure 1.3 in Chapter 1 into an integrated conceptual framework, which is then applied to the City of Gold Coast in Chapter 8. The refinement process also involves adaptation of the planning system to take into account the future oil constraints in providing strategic guidance to local planning schemes, which is applicable to the Gold Coast. Implementation of the conceptual framework in the transformation towards an oil-constrained city is critically dependent upon community acceptance and support for the radical paradigm shift. An indication of acceptance for the medium rise/high density urban residential development form suggested by the grounded theory is therefore provided to complete this section.

The introduction to Chapter 7 suggests that integration of the phenomena into the conceptual framework could be expressed abstractly as **P1** affects **P2** → **P3** where:

P1 = global oil supply depletion causal condition

P2 = sustainable urban form phenomenon

→ symbolises the function of transformation towards a desired outcome

P3 = the desired outcome of oil-constrained sustainable residential forms
within the Australian urban context.

The integrated conceptual framework is derived from the schematic coding model in Figure 6.11 modifying the initial framework in Figure 1.3 to a simplified model in

Figure 7.2 to show this relationship. **Figure 7.3** shows the underlying complex set of relationships. This model is a framework providing the basis of a valid tool for integrating the effects of oil constraints into the urban metabolism theoretical framework for sustainable planning and development. The complex relationship model can be developed as a predictive tool with further research. The models also inform land use planning policies as applied to managing urban growth towards an oil-constrained future.

The conceptual framework in both the simplified (Figure 7.2) and complex form (Figure 7.3) for integrating the effects of oil constraints into the urban metabolism theoretical framework and the supporting research is offered as an original contribution of this thesis research to sustainable planning theory.

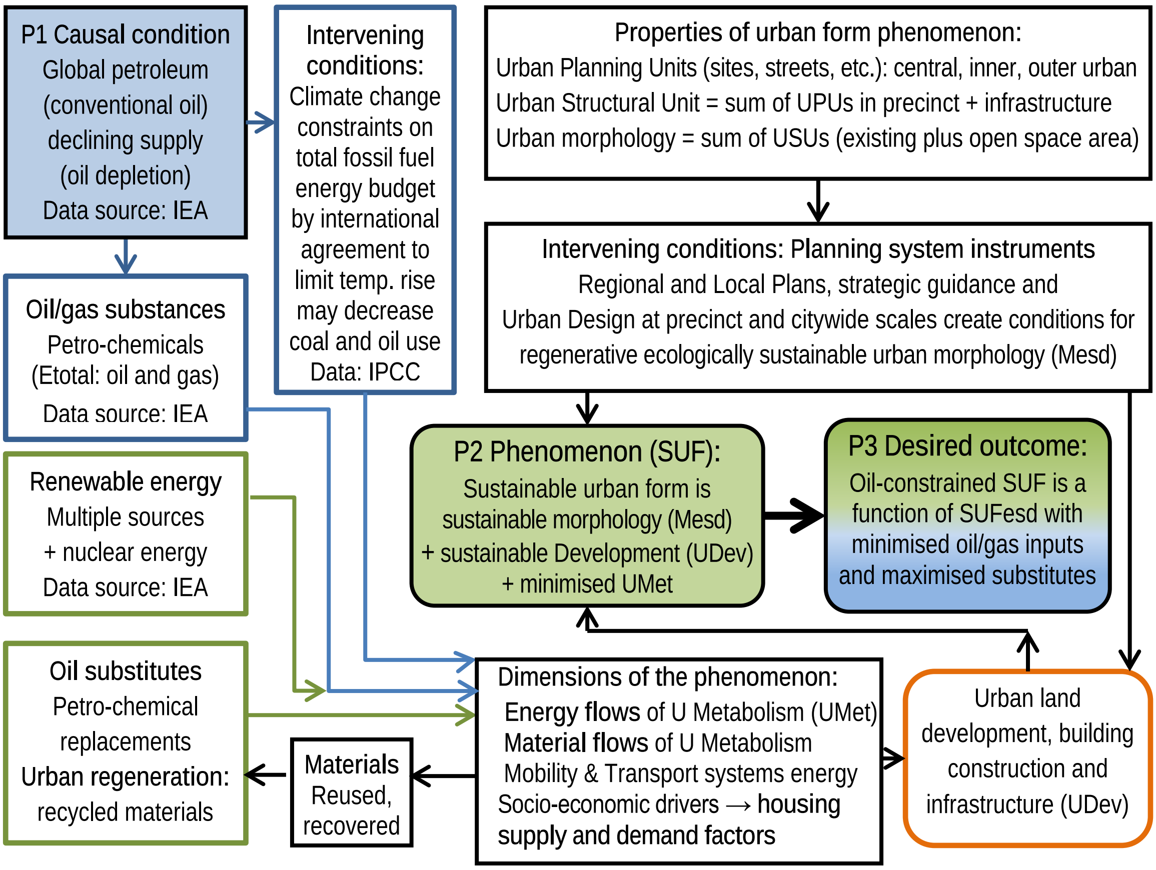


Figure 7.2: Integrated conceptual framework for relationships between oil-related inputs and sustainable urban forms*

Adapted and developed from Gray (2009)

***Legend:** SEH (Socio-economic hierarchy), UMor (Urban morphology city-wide result), USU (Urban structural unit-precinct scale), UDes (Urban fabric and design), UMet (Urban metabolism), Mob-trans (Mobility and transport system factors), Energy-flows (Energy metabolism flows), Geo (Geographic and climatic factors)

One of the emerging issues under grounded theory No. 3 is the negative effect of unearned increases in land values as the mitigation phase of oil depletion increasingly inhibits suburban sprawl led city-wide expansion and accelerates redevelopment pressure in inner urban serviced areas close to public transport. Further research is suggested to review the existing system of freehold land tenure to consider the alternative of residential leasehold as in the development of Canberra (Neutze 1986). This could facilitate regeneration of greyfield areas and controlling urban expansion.

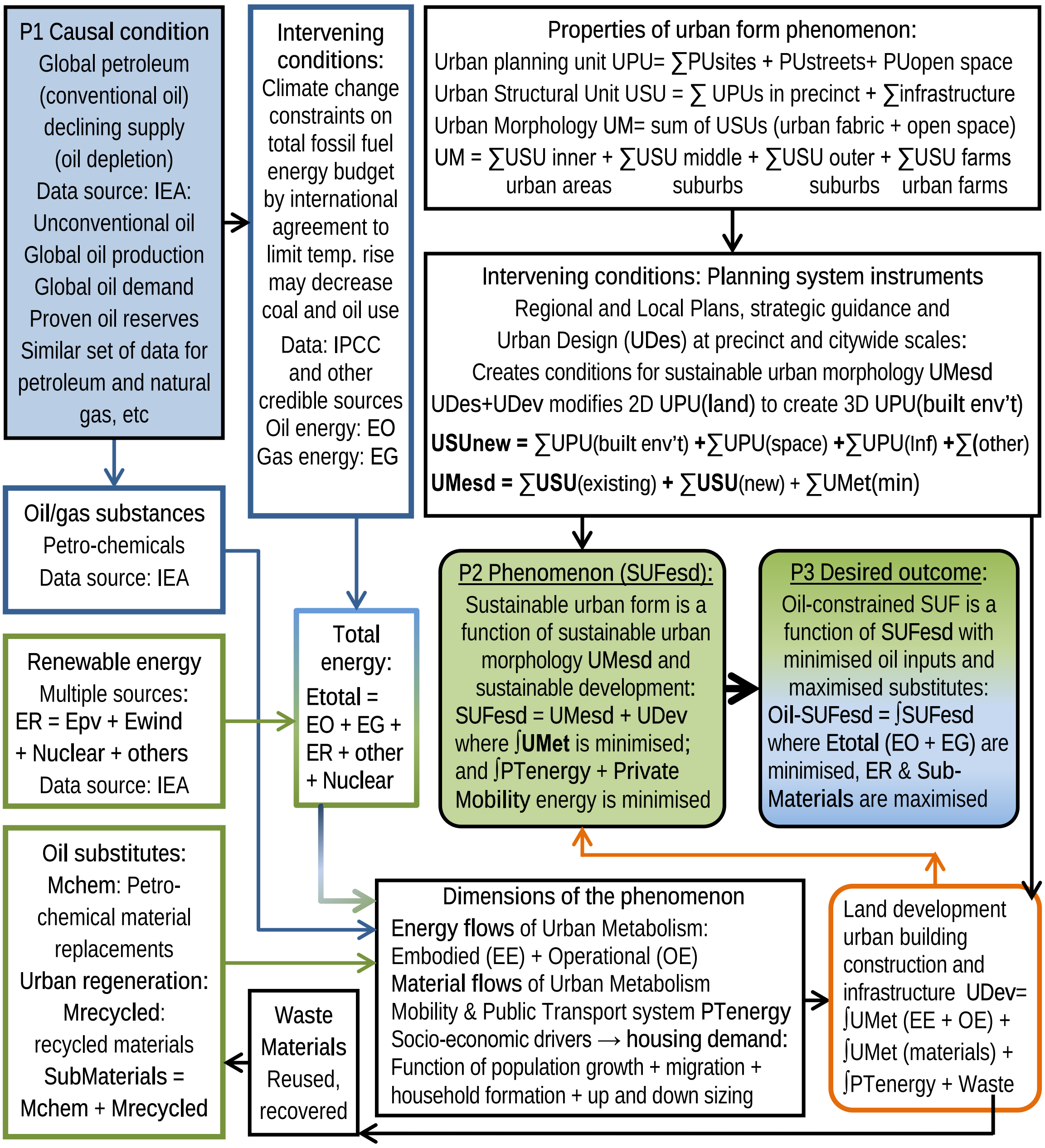


Figure 7.3: Integrated conceptual framework showing detailed relationships between oil-related inputs and sustainable urban forms*

Adapted and developed from Gray (2009)

***Legend: SEH** (Socio-economic hierarchy), **UMor** (Urban morphology city-wide result), **USU** (Urban structural unit- precinct scale), **UDes** (Urban fabric and design), **UMet** (Urban metabolism), **Mob-trans** (Mobility and transport system factors), **Energy-flows** (Energy metabolism flows), **Geo** (Geographic and climatic factors)

The desired outcome is Oil-constrained Sustainable Urban Form (Oil-SUFesd), which is a function of **{**Sustainable Urban Form (SUFesd) where total energy (Etotal: oil and gas) is minimised; and renewable energy (ER) and oil-substitute materials (SubMaterials) are maximised**}**.

7.3.3 Application of grounded theory to Queensland planning reform

Appendix H applies the grounded theories and integrated conceptual framework to Queensland's planning system reform proposals outlined in section 4.3 of Chapter 4.

These theories suggest how adjustments can be made to the planning system to integrate oil depletion strategies into the state planning instruments. The suggested adjustments are summarised in **Table 7**.1 to make a more targeted contribution to the orderly transformation of urban residential forms in the Queensland and wider Australian context towards an oil-constrained future.

Table 7.1: Summary of suggested adjustments to Queensland planning system

7.3.4 Transformation of existing suburbs to an oil constrained future

The grounded theories and refined conceptual framework are also applied to existing suburbs as a summary model to explain the transformation towards an oil-constrained future. The model draws on the characteristics of sustainable cities from section 6.3.2.

PLANNNG SYSTEM COMPONENT	NEGATIVE ASPECTS	SUGGESTED ADJUSTMENTS TO COMPONENT FOR OIL CONSTRAINTS
New State Planning Policy (SPP) in force 2 Dec. 2013: - First completed component - 5 themes, 18 interest areas. - Key themes of liveable communities and housing, and economic growth. - Guidance material yet to come.	SPP is silent on future oil vulnerability and on renewable energy policies. Adequate supply of land suitable for housing implies low density development.	- Recommitment to city-wde compact urban form - Priority weighting is given to densification of inner suburbs and public transport corridors. - Innovative and adaptable housing and urban design favour redevelopment of inner areas as medium rise/ high density apartment buildings in perimeter blocks, or high rise above podiums. - SPP guidance material refers to a released state government oil vulnerability strategy.
New SEQ Regional Plan (RP): - Regional outcomes and policies deal with state interests and conflicts in land use or interests where cannot be addressed by a single local government. - Increased focus on regional economic development. - Regional snapshot (Fact sheet 4) forecasts 803,000 dwellings required by 2031.	Growth in urban footprint for housing land supply. Development appears to be the overriding aim, led by construction of low density housing. New style of RP will weaken oil & climate change issues.	- Consolidation of urban development occurs in existing settlements within existing urban footprint to maximise use of established infrastructure and transport systems at least cost (SPP p. 17). - Renewable energy policies for each sub-region. - Research into replacement building materials and develop natural resource regional management. - Infrastructure development programs refocused to prioritise oil and energy intensive projects in the short to medium term for urban development, public transport and renewable energy systems within each city and sub-regional area.
Qld Planning Provisions ver. 3: - Standardise planning schemes - Subject to revision in reform agenda to be more flexible. - Mandatory strategic framework requirements. - Advocates efficient land use pattern and standard zones.	Standard planning provisions benefits could be weakened. Detached house as self-assessable in all zones is a barrier to higher density.	- Transformation of all existing suburbs to Public-Active Mobility Oriented Development (P-AMOD). - Mandate the 60% infill dwelling target across all inner-middle suburbs for urban renewal. - Incorporate principles of urban metabolism and embodied/operational energy reduction into planning for an efficient land use pattern. - Require 'green street' design to reduce energy, etc
Connecting SEQ 2031 Regional Transport Plan (IRTP). - Existing policies and targets being revised in SEQ RP.	SEQ forecast 30% increase in car trips to 2031 that are 83% of all trips	- 1km/15 min. radius walkable neighbourhood model advocates higher densities in all P-AMOD precincts. - P-AMOD integrated into construction phase of all major projects for access & future goods delivery.
2010 statewide (TOD) Transit Oriented Development guide: - Voluntary guide to planners and developers. - Fully supportive of compact urban development. - Links to IRTP and NGP.	TOD terminology is not used in SPP and could signal a weakening of the concept, or is not considered a state-wide issue.	- P-AMOD becomes a new standard for all urban areas that goes beyond a nodal 400-800m focus to a wider IRTP neighbourhood of 1km/15 minute walking extent to transport node/routes & facilities. - Incorporate principles of urban metabolism and operational energy life cycle into planning for an efficient integrated land use and transport pattern.
Next Generation Planning (NGP) best practice guide: - Voluntary design guide for subdivision/roads/zoning. - 'Smart growth' principles.	Urban transect model shows low density P4 zone as a car dependent but desirable form.	- Condense the P4 zone of the transect to limit the area of low density residential zoning for new greenfield development to reduce mobility stress. - Revise NGP standards as P-AMOD to align with IRTP 1km/15 min. extent walking catchments
State government 2007 oil vulnerability strategy (OVS) & draft Gold Coast Council OVS	Lack of information a significant barrier for land use change	- Finalise state government oil vulnerability strategy and require councils to develop local area OVS as part of the strategic frameworks.

The combination of all these strategies implies not wasting the post-peak oil transition period, but taking immediate leadership and adaptive action at government level with bipartisan support from a fully educated community (Gilbert & Perl 2010: 239). The overall strategy on suburban transformation is therefore dependent on strong government leadership and community awareness raising in the interim post-peak oil period—the mitigation phase of oil depletion—to set clear directions toward the oil-constrained sustainable city. Unfortunately the current political climate and the very low oil price manipulation as at late 2015 are not conducive to such strong leadership, which might hasten the transition for example towards alternative fuels for, and electrification of, the private vehicle fleet. The latter has implications for urban form at the precinct scale for car recharging stations and on-street parking facilities. However, it was concluded from the literature review and Chapter 6 that transport aspects of oil dependency strongly suggest the short to medium term resilience of the existing suburban form is strongly related to an alternative fuels or electric power supply for private car transport.

The revealed insight from theoretical concepts 1-3 is that existing suburbs are likely to survive the post-peak transition period, albeit subject to much higher private transport costs, if suburban communities make *some* degree of transition toward a more resilient state (Chiras & Wann 2003; Yigitcanlar et al. 2005; Dodson & Sipe 2008a; Hopkins 2008, Dunham-Jones & Williamson 2009). The degree of resilience depends on individual and community-wide strategies supported by government planning, designed to adapt to increasing oil vulnerability by:

a. switching to whatever alternative fuel, or electric power technology, are offered by the market for private transport; but also
b. increasing proactively the public transport patronage and active transport usage;
c. redeveloping suburbs at higher densities to support public transport; and also
d. increasing localised sources of food and goods to reduce transport distances.

A conceptual model has been synthesised from the literature review and analysis of sustainable cities to illustrate the application of the refined conceptual frameworks to the transformation of existing suburbs to the oil constrained future:

1. *Adaptive transition* by proactive infill densification, improved public transport and alternative fuel cars, low emission and renewable energy sources
2. *Maladaptive transition* to dysfunctional urban forms by poor community awareness, inadequate policy direction, reactive and delayed action.

This model is offered as a contribution of the thesis to sustainable planning practice. The diagrammatic model at **Figure 7.4** shows two extreme hypothetical adaptive and maladaptive transition scenarios in three phases after the peak oil plateau:

a. *The initial mitigation phase of oil depletion 2008-2018* (during and after the conventional oil peak plateau) could see significant price increases for private car fuels[27]. This will lead to prioritisation of petroleum usage to extend the time horizon for the benefits of the resource and provide oil-based essential materials and petrochemicals relied upon for building components and infrastructure construction, goods manufacturing, public transport system, communications technology, health products and systems, etc. This implies not waiting for the post-peak oil plateau period to be wasted, but taking immediate adaptive action at government level with fully educated community support.

b. *The later adaptation phase 2018-2025 w*hen oil depletion gradually becomes a significant transport constraint on suburban living as fracking of tight-oil declines[28], the full implications of the society's reliance on the oil economy becomes evident. Community action will be complemented by government action to fully develop the public transport system. The transition town movement will become much more active in the community to provide guidance and a rallying point for the energy descent strategies.

c. *The oil-constrained phase after about 2025* with uncertain food and energy security requires complex reorganisation for movement of people, goods and resources. The timely guidance of governments beyond phase (a) and (b) strategies will determine the trajectory of suburbs towards a sustainable or dysfunctional future. Local groups may coordinate community urban farms, or protect private gated enclaves respectively in such futures. Development and market forces favour the wealthy in housing choice and relocation closer to work, public transport system and inner city facilities. Changes to alternative leasehold land tenure could alleviate the impact of rising residential land values.

While suggested time periods in the model are necessarily flexible due to uncertainties in the global economic recovery and tight-oil supply, extending those periods does not invalidate the general premise of the model. The consequences of a delayed recovery, or a weaker than forecast oil demand (e.g. 2009 to 2016), provide a longer transition phase. It allows the introduction of alternative technologies in fuels and energy sources. It also leads to greater risks of complacency and inaction, which could cause the maladaptive scenario to become entrenched in government policy making.

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[27] As noted in section 3.1.1, since the completion of this thesis research, the 2014-16 global oil price manipulation threatening the financial viability of USA tight oil fracking operations gives support to these assertions.

[28] The IEA World Energy Outlook (2015: 132-145) commentary on oil production prospects suggests that: After 2020, even though oil prices reach levels that allow upstream investment to pick up again, the collective output of non-OPEC countries does not resume growth, particularly once production from the United States – so important in the market over the decade to 2020 – reaches a plateau and then enters a gradual decline. By 2040, conventional crude oil accounts for only 66% of total production, compared with 87% in 2000 (IEA 2015: 132-133).

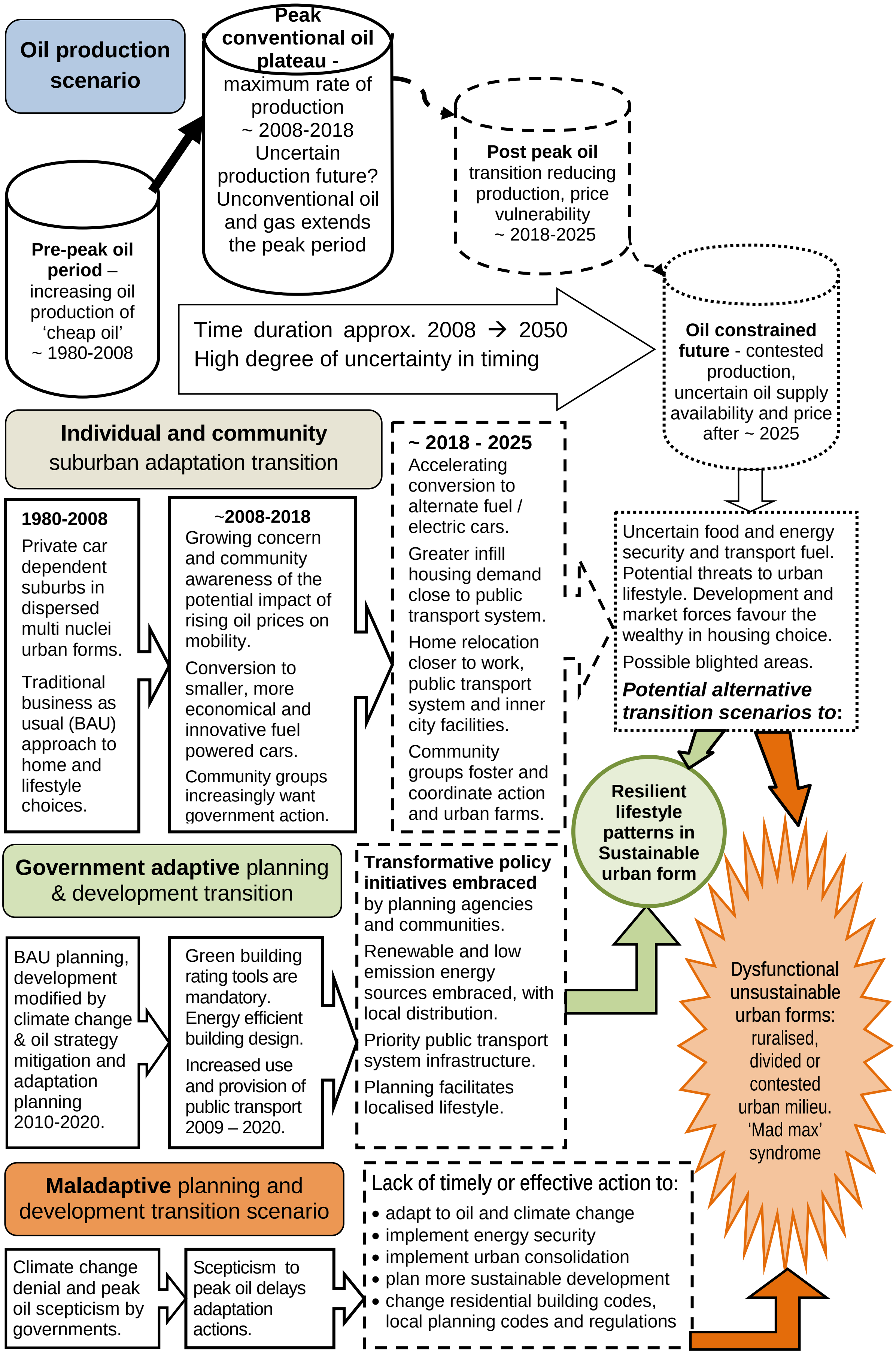

Figure 7.4: Conceptual synthesis model of adaptive and maladaptive transition scenarios towards an oil-constrained future

7.4 Conclusions on planning for oil-constrained residential urban forms

This chapter has addressed research objective 3.2 by developing the theoretical hypotheses derived in Chapter 6 into grounded theory and models about sustainable residential development in the oil-constrained future within the Australian urban context. An abductive approach verifies the theoretical concepts by focused interviews with experts in the planning and development sectors. The grounded theories are used to form a refined integrated conceptual framework, including adjustments to the planning system, which will be applied to the City of Gold Coast in Chapter 8.

Four hypotheses are the basis for grounded theories. The theories operate at different scales of the urban form, involving a timing sequence in their relevance and application suggested in section 7.3.4; evolving in three phases of strategic planning:

1. mitigation phase of conserving oil supply and reducing demand (section 3.2.3);
2. a transitional adaptation phase—the 'transitional city of tomorrow'; then
3. a later transformative phase—towards the 'oil-constrained city of the future'.

The grounded theories are original thesis contributions to sustainable planning theory:

1. *Oil supply constraints will gradually affect all types of urban residential buildings at the site scale:*

   Oil supply constraints potentially affect the sustainability of all new land development and construction of all types of urban residential buildings to varying extents, depending on the materials used and transport-related factors. Materials-related vulnerability may be reduced by adaptation to non-petroleum substitutes. Transport-related vulnerability may be reduced by conversion of diesel powered construction vehicles and machinery to available replacement 'fuels' as a mitigation strategy in the short–medium transitional phase.

2. *Adaptive design is needed for sustainable urban residential forms at the precinct scale:*

   Adaptive design for oil-constrained sustainable urban residential forms at the precinct scale of urban structural units is facilitated most efficiently by medium rise/high density apartment buildings arranged as perimeter/courtyard blocks; in relation to achieving objectives for building material and energy flows, urban density, adaptable functionality, streetscape and public-active mobility oriented development.

3. *Oil depletion will increasingly affect urban communities at middle-outer city scales:*

   The transport-related mitigation phase of oil depletion will increasingly inhibit suburban sprawl led city-wide expansion and accelerate redevelopment pressure in inner urban serviced areas close to public transport. In the later adaptive phase, availability of system-wide alternative energy powered vehicles may mitigate mobility and living cost issues in more affordable housing in existing middle/outer suburbs, as suggested in the suburban transition model in Figure 7.4.

4. *Transformative planning system policies are needed at city-wide and regional scales:*

   As the phenomenon of oil depletion gains international acceptance as a wicked global problem, it will influence government urban land use policies at both city-wide and regional scales within the Queensland and Australian planning context. Transformative guidance on urban metabolic energy flows is linked to state and national policies on transport, renewable energy and climate change mitigation. The planning framework in Figure 4.9 will integrate with a national system. Detailed implementation of inner urban serviced area redevelopment to promote mixed use at higher densities would be subject to planning provisions to suit local conditions.

The grounded theories and the integrated conceptual framework act as a roadmap to guide the strategic direction of the future planning system in leading an orderly transformation of cities to the oil-constrained future. Queensland's planning system is undergoing a profound change of direction toward an expansionary development facilitation role with the following components at the statewide and regional levels (DSDIP 2013a). The reforms cause a planning hiatus that allows suggestions to be made. For the purpose of research objective 3.2, the suggested adjustment of the state Planning Policy (SPP) principles and strategic planning components are summarised in five key principles to improve the capacity of the planning system from an oil and climate viewpoint:

a. The planning system delivers balanced outcomes and gives weight to the impacts of inevitable oil depletion and the benefits of renewable energy in considering the needs of current and future generations, based on best available knowledge.
b. Planning schemes limit the area of low density development in the urban transect (Figure H.3 in Appendix H). Urban consolidation occurs in existing settlements within the existing urban footprint to minimise suburban sprawl and maximise use of established infrastructure and transport systems at least cost to councils, developers, end buyers and the community. QPP3 mandates planning schemes to meet the 60 per cent infill dwelling target advocated in the SEQRP across inner-middle suburbs by urban structural unit plans with mixed use form based zones.
c. Resilience planning of all existing suburbs under the state government and local oil vulnerability strategies transforms most of the city towards an integrated public-active mobility oriented development (P-AMOD) focus. The P-AMOD model extends the 400-800m TOD nodal focus to align with the 15-minute walkable neighbourhood (Queensland 2011: 30) and increases density across the precinct. It therefore proposes a different terminology to distinguish P-AMOD precincts from TOD nodes and corridors, focusing on mobility within the precinct and public transport without the pressure for park-and-ride parking facilities, because the density supports local employment and urban amenities in mixed use form-based zones.
d. Planning schemes incorporate the principles of urban metabolism and life cycle embodied/operational energy to inform evidence based planning of an efficient land use pattern to achieve the sustainable environment required in the SPP.
e. Infrastructure development programs are refocused in the short to medium term to prioritise oil and energy intensive projects for intra-urban and inter-urban development, public transport and renewable energy systems within each city and sub-regional area. This strategy is to minimise the cost rises anticipated to

occur with oil depletion, which could jeopardise the feasibility of major infrastructure projects, and increase resilience to future oil constraints.

In addition to considering the physical, environmental and economic impacts of oil constraints on the built environment, there is also the social question of community acceptance of changes to urban form, which is addressed in the focused interviews. A limited phenomenological research survey by Woodcock et al. (2012: 65-78) on envisioning the compact city finds that buildings up to six storeys in an inner urban Melbourne context could be a readily acceptable level of intensification, which is relevant to this thesis. Yet it clearly relies on the realisation of an attractive streetscape to gain the community acceptance that occurs in the European model. It is also related to the 'green street' concept that better integrates the building-streetscape interface. Another aspect on community acceptance is in relation to future land tenure to reduce housing stress in redeveloping urban greyfield areas. Further research is suggested to review the existing system of freehold land tenure to consider the alternative of residential leasehold as in the development of Canberra, as analysed by Neutze (1986).

The planning provisions suggested in Table 7.1 applicable to the reference case study City of Gold Coast would include strategic guidance in oil depletion adaptation policies, an adjusted SEQ Regional Plan and mandatory QPPs. Local government strategic frameworks under the QPPs could be guided by the urban metabolism model Figure 7.4 derived from the integrated conceptual framework in Figure 7.2. The framework and model will inform the application of the grounded theories in Chapter 8 to the City of Gold Coast.

Chapter 8

Future urban forms for an oil-constrained Gold Coast

Most decisive of all, cities, like mankind, renew themselves unit by unit in a slow, timebound metabolic process. Sybil Moholy-Nagy, *Matrix of Man* (1968)

This Chapter addresses research question 3.3 by applying the grounded theory, integrated conceptual framework and the adjusted Queensland planning framework summarised in Table 7.1 to the reference City of Gold Coast. The aim is to provide guidance for transformation towards oil-constrained sustainable urban residential forms. The first section overviews the city planning context and highlights some relevant current and future challenges. Section two suggests suitable models for sustainable development that could be applied in the city. The final sections envision planning towards a ‘transitional city of tomorrow’ and an ‘oil-constrained city of the future’.

8.1 Application of grounded theories to City of Gold Coast

This section applies the grounded theory, integrated conceptual framework and the adjusted planning system policies to the City of Gold Coast circumstances. The grounded theories operate at different scales of the urban form, involving a sequential timing in their relevance and application. Coincidentally the theories progress in the morphological scale of urban structural units from the building lot to precinct to city-wide to metropolitan region scale and beyond. These temporal and spatial scales suggest strategic planning will evolve in three phases. After the initial mitigation phase, the planning related phases are: towards a transitional city of tomorrow; and later an oil-constrained city of the future.

The grounded theories tailored to the Gold Coast sub-region are:

1. *Oil constraints gradually affect all types of urban residential buildings at site scale:*
   Oil supply constraints potentially affect the sustainability of all greenfield land development (such as at Coomera district) and construction of all types of urban residential buildings to varying extents, depending on the materials used and transport-related factors. Materials-related vulnerability may be reduced by adaptation to non-petroleum substitutes produced in the well-developed local economy. Transport-related vulnerability may be reduced by conversion of diesel powered construction vehicles and machinery to available replacement ‘fuels’ and electric power as mitigation and adaptation strategies in the transitional phase.

2. *Adaptive design is needed for sustainable urban residential forms at precinct scale:*
   Adaptive design for oil-constrained sustainable urban residential forms at the precinct scale of urban structural units is facilitated most efficiently by medium rise /high density apartment buildings, possibly arranged as perimeter/courtyard blocks; in relation to achieving objectives for building material and energy flows, urban

density, adaptable functionality, streetscape and public-active mobility oriented development in the 'urban neighbourhood' sector of the urban transect (see Figure 8.5).

3. *Oil depletion will increasingly affect urban communities at middle-outer city scales:*

   The transport-related mitigation phase of oil depletion will increasingly inhibit suburban sprawl led city-wide expansion and accelerate redevelopment pressure in inner urban serviced areas close to public transport. In the transitional adaptive phase, availability of system-wide replacement 'fuels' and electric powered vehicles may mitigate mobility and living cost issues in more affordable housing in existing middle/outer suburbs, as suggested in the suburban transition model in Figure 7.4 in section 7.3.4. However, an alternative scenario would feature abandonment of suburban housing as in Detroit USA in recent years (e.g. Bittman 2011).

4. *Transformative planning policies are needed at city-wide and regional scales:*

   As the phenomenon of oil depletion gains international acceptance as a wicked global problem, it will influence government urban land use policies at both city-wide and regional scales within the Gold Coast City planning scheme context. Transformative guidance on urban metabolic energy flows is linked to Queensland and national policies on transport, renewable energy and climate change mitigation. Detailed implementation of redevelopment of early-mid 1900s inner urban areas to promote mixed use at higher densities would be subject to planning provisions to suit local conditions.

   In the Queensland context these provisions would include strategic guidance in oil depletion adaptation policies, an adjusted SEQ Regional Plan and mandatory Queensland Planning Provisions (QPPs). Local government strategic frameworks under the QPPs would be guided by urban metabolism models derived from the integrated conceptual framework for the City of Gold Coast at Figure 7.5 in section 7.4.

8.1.1 City planning context and challenges

While old European cities may be attractive from physical, environmental, social and aesthetic viewpoints, they are not a universally applicable recipe for Australian cities devoid of that heritage—especially a twentieth-century tourism and lifestyle city like the Gold Coast (Prideaux 2004) that has a subtropical mild–hot climate. The urban form is not at all like the old European cities and there would appear to be no compelling reason to directly emulate those energy efficient cities surveyed in Chapter 6, although the characteristics of an oil-constrained city are relevant.

However, section 4.3.3 indicates that the decision to make Southport the Gold Coast CBD, with a declaration in October 2013 of the Priority Development Area (PDA) and the later adopted Land Use Plan (LUP), is a turning point. The proposed character of development in the CBD residential precinct 2 (Figure 4.13 in section 4.3.3) is to be 'perimeter block or iconic high rise towers set above a podium' in a 'highly urbanised environment that is activated at ground level by design and use' (DSDIP 2013e: 25).

Perimeter blocks, as in the studied European cities, are coincidentally the preferred adaptive design in grounded theory No. 2 for oil-constrained sustainable urban residential forms. If the LUP intent were to be implemented with perimeter blocks, it would provide a valuable demonstration site in the Southport PDA to validate application of the theory. It would, however, need contiguous blocks to be an effective streetscape. The alternative high rise podium form is already common in the Surfers Paradise area and emulates notable sustainable cities such as Vancouver CBD.

As noted in section 4.3.3, the draft *Bold Future Planning Scheme* (Gold Coast City Council 2012) has been withdrawn and developed into a new style *City Plan* scheme to make the city 'the most liveable, affordable and prosperous place in Australia' (Mayor Tate, media release, 5 September 2012). The strategic framework advocates a city 'shaped by clever design' comprising an urban settlement pattern of activity centres, industry and business areas, transit supportive urban neighbourhoods, suburban neighbourhoods and new communities (GCCC 2012: Part 3: 36). The plan had not been redrafted as at late 2015 because of the challenges of ongoing planning reforms and adoption of version 3 of the QPP. There is still an opportunity for the council to release the oil vulnerability strategy, so as to incorporate it into the final scheme.

The oil-related planning and development challenges include the following[29]:

a. Section 4.2.5 notes that the city population is forecast by Queensland Treasury and Trade (2013) to continue growing at 1.9 per cent, rising from 513,954 in 2011 to nearly 800,000 by 2031. This growth will require the order of 101,000 new dwellings at the current occupancy rate of 2.83; a 55% increase on 181,620 in 2011. Tourism and construction led economic and employment affect the city population growth and therefore the fluctuating demand for land and housing.
b. Medium and high intensity housing is expected in the draft planning scheme to occur within activity centres and transit supportive urban neighbourhoods. Fortunately, apartment living is an accepted feature of the Gold Coast coastal strip. This makes such housing more viable, say in comparison with Brisbane to the north. An extract from the GCCC community profile-social atlas at Figure 4.8 in section 4.2.5 shows that in 2011 43 per cent of all dwellings at the Gold Coast were medium – high density, compared to 22 per cent in Brisbane; with a corresponding decrease in the proportion of detached houses (GCCC 2013b). However, the existing activity centres have not been well integrated with medium–high density accommodation and a major redevelopment program would be needed to achieve the intent of the (draft) plan for the city.
c. The draft plan acknowledges that the suburban neighbourhood areas will remain 'extensively low-intensity residential environments with a focus on retaining and enhancing neighbourhood character' (GCCC 2012: Part 3: 36). These traditional

[29] Since this research was completed, [see footnote in section 4.2.5] the *City Plan* was adopted on 2 February 2016 and was strongly informed by the *Bold Futures* draft plan, so these challenges are still relevant.

residential areas dominate the city, so are vulnerable to the future oil depletion shocks illustrated in the yellow and red zones of Figure 3.1 in section 3.1.1.

d. The developer led suburban expansion of low density housing generally northwards through the Coomera district (see Figure 8.10) is slow to meet the challenges of changing demography towards an older population and lone-person households. New development in Coomera is intended to be developed as suburban and transit supportive urban neighbourhoods around the Coomera Principal Activity Centre. However, current detached housing close to the centre fails to achieve an intended minimum yield of between 15 to 33 dwellings per net hectare.
e. The urban renewal process in the aging 'greyfield' middle suburbs developed in the mid-1900s is poorly coordinated and exacerbates the resident resistance (NIMBY syndrome) to higher density developer led site amalgamation projects.
f. The residential property and building industries are important barriers to developing to a more sustainable urban form. Industry compartmentalisation means that residential builders construct homes for large scale property developer land and house packages. Commercial scale builders construct medium and high rise projects for developers. A greater proportion of medium and high rise buildings will adversely affect the livelihoods of domestic scale contractors.
g. The transport system is a key factor in all development and construction. All building materials and components are moved by road transport. The Gold Coast heavy rail system is not designed for freight haulage and in any case serves only the northern, western and eventually southern suburbs. The light rail connection will improve the mid coastal link in the 2020s, but the urban structure is poorly designed and geographically fragmented, with waterways and residential canal estates, for a dense light rail network. The light rail single route will have little impact on most intra-city travel. The polycentric city employment structure makes it heavily car dependent, even with an extensive bus network.
h. City planning suffers from the legacy of the pre-1990s coastal city and adjoining hinterland shire council, with differing philosophies on the supply of land and housing, as well as city-wide commercial development and transport strategies.

These challenges are not insurmountable in the short term and the draft plan addresses housing demand by proposing development to be prioritised within activity centres and transit supportive urban neighbourhoods. No theoretical barriers to future sustainable development and building techniques have been identified in the current and draft planning schemes review. The draft strategic framework in fact espouses the Next Generation Planning principles discussed in section 2.2.3 and reviewed in Appendix H. Inner urban areas such as Labrador noted in section 4.2.5 would be obvious candidates for adaptive oil depletion strategies. The draft scheme generally complies with the requirements of the QPP3 criteria outlined in section 4.2.2. However, the strategic residential concepts related to greenfield development in areas such as

Coomera are considered to be aspirational goals, from personal experience of living in that area. The supply of greenfield land is likely to be exhausted by 2017 according to the draft plan, with its predominant urban form being extensively low-intensity residential environments. In the medium to long term, however, the grounded theories will become more significant as oil supply declines.

8.1.2 Suggested planning responses to oil depletion

The major challenges to transforming the city urban development are considered to increase under conditions of declining oil supply. The following suggested planning responses invoke the grounded theories and adjustments to the planning system.

The forecast is to construct the order of 101,000 new dwellings in a 20 year period. This does not take into account new household formation, falling occupancy rates and the low occupancy rates for apartments, which are about 1–1.5 in the coastal areas (see Appendix C). That is a major challenge if, as grounded theory 1 suggests: oil supply constraints potentially affect the sustainability of all new land development and construction of all types of residential buildings to varying extents.

Grounded theory 3 suggests that the rising transport costs-related mitigation phase of oil depletion will increasingly inhibit suburban sprawl led city-wide expansion. In the case of the Gold Coast housing demand pressures and limited greenfield land availability, the prudent planning response suggested in section H.7 of Appendix H is to limit the area of low density residential zone in new greenfield suburban neighbourhood areas. In the later adaptive phase, availability of system-wide replacement fuels and vehicles may mitigate mobility and living cost issues in more affordable housing in existing middle/ outer suburbs. However, it is not considered prudent to rely on the technological solutions in a globally competitive environment when demand for alternative fuels and vehicle technology will grow exponentially.

Hence the related second consequence in grounded theory 3 is applicable: redevelopment pressure will accelerate in inner urban serviced areas close to public transport. The abandoned *Bold Future* strategic framework aligns with this effect by adopting the adjusted SPP strategy to consolidate urban development in existing activity centres within the current urban footprint to minimise suburban sprawl and maximise use of established infrastructure and transport systems at least cost to councils, developers, end buyers and the community. The strategic framework also aligns with the adjusted QPP3 direction to mandate the 60 per cent infill dwelling target advocated in the SEQRP across inner-middle suburbs. This would be achieved by integrated urban structural unit plans for the activity centres and corridors with the mixed use zones proposed in the *Bold Future* plan (GCCC 2012: Part 3: 24).

In relation to the medium and high intensity housing expected in the draft planning scheme to occur within activity centres and transit supportive urban neighbourhoods, grounded theory 2 is applicable. Adaptive design for oil-constrained sustainable urban residential forms at the precinct scale of activity centres and transit supportive structural units would be facilitated most efficiently by medium rise/high density apartment buildings. They would be arranged as perimeter blocks or above commercial podiums, as in the Southport PDA ILUP for the CBD residential precinct.

Both the community and the property development industry need to be educated by intensive engagement programs that this solution will achieve the objectives for building material and energy flows, urban density, adaptable functionality, and public-active mobility oriented development. The evidence base for such planning includes the sustainable planning review in section 4.2.4 and Appendix H that planning schemes incorporate the principles of urban metabolism and embodied/operational energy life cycle to inform an efficient land use pattern to achieve the sustainable environment required in the SPP. Transformative guidance on urban metabolic energy flows would be linked to state and national policies on transport, renewable energy and climate change adaptation, as well as best practice information. This would be assisted by the council links with academic and research organisations such as the Griffith University Urban Research Program and National Climate Change Adaptation Research Facility.

Redevelopment of activity centres and transit supportive urban neighbourhoods as proposed in the *Bold Future* plan would be assisted by the adjustments to the planning system suggesting resilience planning of all existing suburbs under the state government and local oil vulnerability strategies (OVS). The Gold Coast has a draft OVS that could assist in the process of transforming most of the city to an integrated public-active mobility oriented development (P-AMOD) focus (see section 4.2.4). The P-AMOD model discussed in section 7.1.3 extends the 400-800m TOD nodal focus of the Next Generation Planning model to a one kilometre/15 minute walking radius and increases density across every urban precinct. The *Bold Future* plan appears to adopt the NGP model and TOD guidelines of *Connecting SEQ 2031* (Queensland 2011).

The city-wide detailed implementation of inner urban serviced area redevelopment to promote mixed use at higher densities under the *Bold Future* plan invokes grounded theory 4 to better coordinate urban renewal process in the aging 'greyfield' middle suburbs developed in the mid-1900s. Local planning would be subject to planning provisions to suit local conditions, including strategic guidance on oil depletion adaptation policies through community engagement programs to address the resident resistance to higher density council supported or led site amalgamation projects.

Grounded theory 1 also advocates strategic guidance on oil depletion adaptation policies through community engagement programs are needed in relation to materials-related vulnerability risks that may be reduced by adaptation to non-petroleum substitutes. This is considered important to assist the building and construction sector in making adjustments to changing circumstances, and overcome the residential property development industry barriers to developing to more sustainable urban forms. It is particularly relevant to the challenge of an increasing proportion of commercial scale apartment buildings that require different skill sets and contractual arrangements. The council would also undertake research into replacement building materials and develop natural resource regional management programs, as suggested in Table 7.1 in Chapter 7 (also in Appendix H).

These planning responses demonstrate some ways in which the local government planning system strategically can facilitate the transformation to the future using the grounded theories. An overview of some planning models is made in the next section to illustrate the planning tools relevant to achieving the desired outcome of oil-constrained sustainable urban residential forms, as established in the integrated conceptual framework in section 7.3. The models are tailored to the Gold Coast residential environment as the morphological expression of compact urban form.

8.2 Sustainable development models

The starting point to achieve an energy efficient compact urban form that minimises oil inputs and maximises mobility is through ecologically sustainable urban design. Much has been written about sustainable development, as noted in Chapter 2. It is not intended to make an exposition of well documented planning models, but to focus on application of the grounded theory and integrated conceptual framework to the issues.

Building construction is an energy-dependent activity, like nearly all other economic activity. In the face of oil constraints, there will be scope for efficiency improvements, but it is unlikely that the industry could isolate itself from more general economy-wide impacts of energy evolution. (AGO 2006: 71-72). Hence new ways of figuratively sewing the urban fabric are necessary that go beyond the general planning policy statements.

An alternative approach to dwelling density uses urban metabolism and life cycle analysis theory to investigate the embodied and operational energy consumption and efficiency in different types of residential buildings, to determine the more sustainable dwelling types and how to assemble them into an equally sustainable precinct or urban structural unit[30]. Grounded theory 2 derived from this research and case study considers that achieving objectives for building material and energy flows, urban density, adaptable functionality at the precinct scale of urban structural units is facilitated most efficiently by medium rise/high density apartment buildings arranged as perimeter blocks. Yet it is not the only solution beyond the inner suburbs. Rickwood (2009: 153) poses ‘the base question we should be trying to answer is: What are the energy use implications of particular housing strategies and, importantly which strategies are achievable?’ He acknowledges the social factor of acceptability as an important criterion in policy setting, so as not to coerce people to make housing choices they oppose. This applies particularly to higher density apartment living for families and conversely to child free couples forced into suburban detached dwellings. Such considerations lead to a suite of alternative residential forms that may cope with oil depletion in different ways, including the following concepts at various urban scales:

[30] It is relevant to note that in the proposed planning legislation, ‘ecological sustainability’ is identified as a core purpose of the proposed Act ‘as the outcome to be achieved by the Act's land use planning and development assessment system’ (Queensland Parliament 2016: 10-11)

1. Cohousing (McCamant et al. 1994; Hanson 1996);
2. New urbanism and smart growth (Calthorpe 1993; Duany et al. 2000, 2010)
3. Transit oriented development (Dunphy et al. 2004; Dittmar & Ohland 2004; Weller 2009)
4. Urban villages (Neal 2003)
5. Regenerative eco cities approach (Register 2006);
6. Transition Towns Movement (Hopkins 2008).

8.2.1 Cohousing

Along with architects McCamant and Durrett (1994), Chris Hanson (1996) was one of the pioneers of cohousing designers in the USA, who imported the idea of living in community with privacy from Denmark in the 1980s. The cohousing developments may have about 10-50 dwellings plus a key feature—the common house—for occasional shared meals and community activities. These shared activities are the glue bonding the community. Residents manage the property and share responsibility for maintenance and activities. The common house complements private dwellings of diverse types, which depending on individual needs can range from bedsitter studios to large family houses. Buildings are clustered around the common house, or an integrated dedicated area within an apartment complex. Generally on-site car parking is subordinated to pedestrian movement and car sharing is a future-oriented practice.

The research included inspection of two well established cohousing communities in Vancouver: Cranberry Commons and Quayside Village. Each of these was designed by Hanson as a mixed townhouse/apartment complex of 21 units of 2-3 bedrooms and integrated common house facilities. The communities in both projects claim they are successful and meet the desired objectives of private living in a shared lifestyle. Turnover of units has been low and on-sales have increased property values more than surrounding units. **Figure 8.1** shows the Quayside Village with a Car-2-Go share car outside and an integrated, separately owned corner shop behind the yellow awning.

Figure 8.1: Main façade of Quayside Village Cohousing, Vancouver

Source: Photo by the author August 2013

Residents are generally owner occupiers, but in some projects may rent affordable units. Most cohousing communities have no special selection criteria, but most residents tend to be community minded, committed to reducing energy and waste, and growing food (Hanson 1996: 15, 196; Cohousing Association USA website). The inherent flexibility of the cohousing concept is the key to its value for multi-generation housing, which can be integrated into sustainable urban forms such as urban villages and transition towns, as well as into conventional neighbourhoods or mixed use areas. The concept is well established in the USA, but is still an interesting novelty in Australia.

Relevance: Cohousing aligns with grounded theories 1 and 2 and the adjusted planning system principles to incorporate urban metabolism and life cycle embodied/ operational energy concepts to achieve efficient land use in a sustainable environment.

8.2.2 New urbanism and smart growth

Since the mid-1980s many planning practitioners have advocated principles of 'smart growth' as a semi-technological path to urban sustainability, evolving out of new urbanism (Van der Ryn & Calthorpe 1986; Calthorpe 1993; Duany et al. 2000, 2010; Cuthbert 2003; Wheeler 2004). Wheeler (2004: 15) explains that 'smart growth focused especially on mechanisms to promote more compact, economically efficient urban development', by limiting the urban footprint and densifying the inner areas to facilitate public transport. Walkability, diverse and mixed use development are hallmarks of this theme. It also seeks to shift the development paradigm from urban expansion to urban revitalisation. Smart growth promotes the concept of the urban transect and supports transit oriented development to maximise transport efficiency. It has been adapted into the Next Generation Planning handbook (reviewed in section 8.2.7) to embrace the principles noted above and creating 'quality housing for people of all income levels' (Council of Mayors (SEQ) 2011: 3). Barton (2000: 82) and Register (2006) are critical of the movement's dualistic approach to urban design in the *Charter of the New Urbanism* (Duany et al. 2010) by only marginally raising densities and clinging onto cars. Register asks 'how well can slightly more dense suburban centers work if the assumption is that cars will be needed in addition to whatever transit is encouraged? … as if the process of design starts with the car' (2006: 122). He cites Calthorpe as calling new urbanism a 'bridge strategy', but suggesting that 'solar and other alternative technologies are tools for new settlement patterns rather than compensations for the faults of the old' (Register 2006: 122, 124). Smart city strategies are a feature of European (e.g. Freiburg and Vienna) and other cities (e.g. Portland and Vancouver) noted in Chapter 6, but are not fully adopted in the Gold Coast draft *Bold Future* plan. Smart growth embraces innovative technological solutions of the knowledge economy and renewable energy, which are central to a city shaped by clever design.

Relevance: Smart growth potentially aligns with grounded theories 2, 3 and 4 and the adjusted planning system principles a – d of section 7.4.

8.2.3 Transit oriented development

Transit oriented development (TOD) introduced in section 4.2.4 has been a feature of planning since the late 1990s (e.g. Calthorpe 1993; Dittmar & Ohland 2004; Dunphy 2004). It is a cornerstone of the SEQ Regional Plan and has been published as a guide for Queensland urban development, as described in Appendix H.6. 'TOD will be based around frequent and high-capacity public transport systems, primarily rail and busway. These systems will connect transit precincts of different scales and types in transit corridors. The goal is to create a network of vibrant, diverse communities and reduce reliance on private motor vehicles' (TOD guide: 5). However, the practice of TOD is somewhat less encouraging than the theoretical ideal. The development of heavy rail based TODs in Brisbane is problematic because of multiple land tenure and regulation; and would be at Nerang and Robina on the Gold Coast due to extensive car parking and remoteness of the station from the retail core. This view is reinforced by Barton (2000: 131) who suggests that urban TOD designed with expanded commercial services beyond a local catchment satisfy a market demand that relates more to car based patrons.

In the Gold Coast context TOD is already an accepted planning principle and a key element in the *Bold Future* plan. The Gold Coast light rail system underpins the high density redevelopment of the Southport PDA as the regional CBD, noted in section 4.3.3. The value of retrofitting this costly infrastructure is dependent on close integration of the light rail with heavy rail and bus transport modes, then extending the system to service more of the inner and middle suburbs.

Relevance: TOD aligns with key grounded theories 2, 3 and 4 and the adjusted planning system principles b – e of section 7.4.

8.2.4 Urban villages

The urban village is another concept for modern neighbourhoods. In the view of Sue Roaf (in Satterthwaite 1999: 235), proponents of urban villages believe 'reducing automobile dependence is the most important urban design consideration'. A modern urban village is normally a neighbourhood within a city that has key characteristics of a traditional self-contained village including a mix of land uses, high quality public transport, good urban design and attractive public spaces. Hence urban villages hark back to the traditional walking villages and market towns of UK and Europe and the garden city movement of Ebenezer Howard in the early 1900s. Barton (2000: 79) envisions urban villages as part of urban regeneration and suggests that 'the objective clearly is that *whole* [sic] urban neighbourhoods, townships … are evolved towards sustainability' (Barton 2000: 74). Cohousing could also be embedded in urban villages.

The author has visited his family in villages and market towns in the east midlands of England, about one hour north of London by express train. Market Harborough in Leicestershire and Stamford in Lincolnshire are illustrated in **Figures 8.2** and **8.3** and are attractive commuting towns. These and similar towns in the Cotswolds are also picturesque tourist magnets (that underpins local economies), but suffer traffic chaos.

Figure 8.2: Aerial photo of central Market Harborough, Leicestershire UK

Source: Stamford library with permission

Figure 8.3: pictorial schematic of central Stamford in Lincolnshire UK

Source: Stamford library with permission

Harborough has existed as a market town since the 1200s and has about a 21,000 population (Harborough District Council 2011: 9). Stamford was founded in the 1000s and now has about 20,000 population in an area of 797 ha at a gross density of 24.7

persons per ha (Stamford Town Council 2013: 17, 34). It has been redeveloped over the centuries, but the Georgian stone buildings and the 18th and early 19th century 2-3 storeys housing were preserved by the whole town being declared the first Conservation Area in England in 1967. This declaration has made the town an architectural museum that prevented further peripheral sprawl. Coincidentally these towns are also designated Transition Towns—discussed below. Both Harborough and Stamford are equivalent in population to the Biggera Waters–Labrador locality of the Gold Coast. The concept of urban villages is an attractive utopian ideal that in the case of these historic towns has taken a century to develop. Both Harborough and Stamford suffer from some sprawl; yet are sufficiently large with a productive hinterland to be self-sufficient in basic foods, though in reality are not so because of modern eating lifestyles. The central parts are definitely urban walkable enclaves.

Relevance: The urban village concept potentially aligns with grounded theories 2 and 4 and the adjusted planning system principles b – d of section 7.4.

8.2.5 Regenerative ecocities approach

Richard Register (2006) has written extensively on the subject of ecocities and imagined them as three dimensional, urban living structures with strong ecological foundations and systems. The term was devised by Register to include the principles: 'build the city like the living system it is; make the city's function fit with the patterns of evolution; follow the builder's sequence – start with the foundation with a land use pattern that supports the healthy anatomy of the whole city; reverse the transportation hierarchy to plan for pedestrians first, and lastly cars; build soils and enhance biodiversity (Register 2006: 183-184). There is no one size fits all approach to design, as each community needs to fit in with its bioregion surroundings and functions. His eco city designs were architectural creations drawing on historical themes, but using modern technologies such as light rail and active transport in compact multi-use forms; passive design principles to optimize energy performance; to create a rich cultural and natural landscape. Ecocity principles align well with the more recent concept of regenerative cities (Girardet 2008, 2013) advocating a paradigm shift from 'Petropolis' to 'Ecopolis'—which mimics the restorative relationships of 'circular metabolic systems found in nature' noted in section 2.3.

The Gold Coast would not be considered to be an ecocity as it has been developed as an ostentatious tourist place for consumption of products and experiences, and a lifestyle playground for the wealthy—evidenced in the extensive canal estates and quality high rise apartments. As inbound international tourism travel becomes problematic, the city image will need to be reinvented and this is one option for consideration.

Relevance: The ecocity concept potentially aligns with grounded theories 1, 3 and 4 and the adjusted planning system principles b – d of section 7.4. The density and urban form of the ecocity are likely to be too low to align with grounded theory 2 unless the principle of urban consolidation is strongly enforced.

8.2.6 Transition Towns movement

The Transition Towns movement originated in Totnes UK and was championed by Rob Hopkins (2008). It has spread worldwide and is developing in Australian cities as a community driven initiative to adapt to peak oil by lowering energy usage and to climate change by reducing greenhouse gas emissions. It has other social cohesion benefits, which are part of the attraction of local communities joining together to make the transition towards a more resilient society.

A visit to Totnes in Devon and Market Harborough in Leicestershire enabled interviews with members of the Transition Town organising committee. The world-wide movement is acknowledged to still be in a fledgling stage, but the principles are in place for future expansion of the concepts. The objectives of the movement are illustrated in the Totnes website below in **Figure 8.4**. The photo shows the Totnes Pound local currency, which is a key feature in supporting the local economy and replaces the bartering mechanism used to share local resources. The contrast between these towns is the high level of support by the Totnes Council and the apathetic stance of the Harborough Council. (Woodiwiss, D, 2013, interview, 2 June). The latter arises because of the high growth rate in Harborough of 10-15 per cent in three years and pressure for housing, as confirmed by a council planner.

Relevance: The Transition Towns philosophy aligns strongly with grounded theories 1 – 3.

Figure 8.4: Objectives of transition town movement in Totnes, Devon, UK

Source: Totnes website (2011)

8.2.7 Next Generation Planning adapted for an oil-constrained future

The Next Generation Planning (NGP) Handbook that was introduced in section 2.2.3 of Chapter 2 is a non-statutory guide for planners in South East Queensland (SEQ) cities including the City of Gold Coast, but it is generally applicable elsewhere with suitable modification. The guide draws heavily on new urbanism theory and smart growth principles noted in section 8.2.2. The NGP Handbook 'focuses on planning for new urban and suburban communities, but can be relevant to existing areas' (Council of Mayors (SEQ) 2011: 1). It identifies four concepts: affordable living; smart growth principles; form-based codes; and an SEQ Place Model transect as an illustrative concept.

The Place Model is based on seven main place types. **Figure 8.5** shows part of the urban transect, omitting the very low density exurbs and hinterland villages. While the NGP promotes a more compact urban form achieved in next generation suburban (P4: 15-30du/ha) and urban (P5: 30-100+du/ha) neighbourhoods, they are aspirational models. As suggested in section 7, the diagrammatic 5 minute walkable radius catchments are too small for an oil-constrained future. The P4 zone is a low density residential zone, which in QPP3 predominantly comprises detached dwelling houses. This zone generally perpetrates the existing low density, car-dependent suburban character of SEQ cities. The model in Figure 8.5 cannot show the proportional spatial extent of each of the zones.

Suggested adjustments to component for oil-constraints:

- It is suggested to condense the transect P4 zone to limit the area of low density residential zone in new greenfield development to reduce mobility stress.
- It is suggested that NGP standards be revised as P-AMOD to align with IRTP one kilometre/15 minute radius walking catchments in urban renewal suburbs.

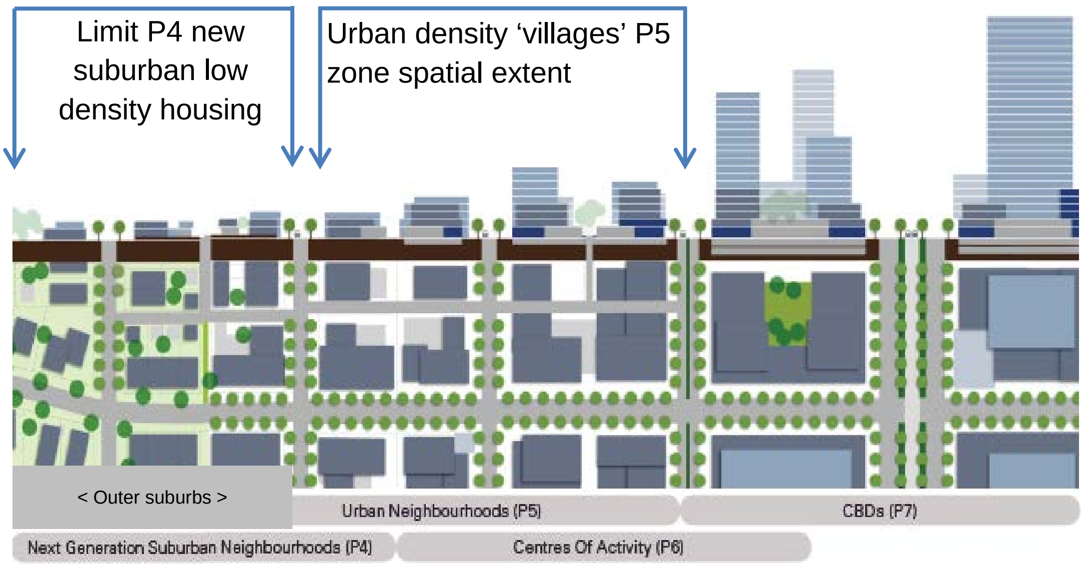

Figure 8.5: Conceptualised urban transect of South East Queensland cities

Source: Adapted from Council of Mayors (SEQ) (2011: 10)

8.2.8 Sustainable urban planning at all urban scales

Many urban theorists including Barton (2000), Neal (2003), Riddell (2004), Jenks and Dempsey (2005), Register (2006), Newman and Jennings 2008) and Newman et al. (2009) have developed principles of sustainable planning that incorporate all the above concepts, partially summarised in the NGP Handbook principles. Riddell regards the eco-village as a utopian ideal ecological form of new urbanism more suited to the peri-urban zone around cities (2004: 223). Barton and Register argue that the ecologically sustainable development principles should be applied across the whole urban area.

These alternative urban patterns have all been advanced as being more sustainable in relation to climate change, enhanced liveability, resource conservation and increased transport efficiencies. Some such as new urbanism has a foot in both the pedestrian and the car dominated domains. At the other end of the sustainability scale, ecocity advocates call for fundamental realignment of urban metabolic patterns from Petropolis to resilient regenerative Ecopolis—which mimics the restorative relationships of circular metabolic systems found in nature. Transition towns activists also seek to guide transformation toward a more resilient society as a community led movement. Cohousing communities fit comfortably into all the development patterns.

The research suggests that the urban infrastructure supporting suburban lifestyles, employment and facilities may gradually become problematic, even in the post-modern knowledge economies. it is acknowledged that there is a temporal aspect to the urban design evolution of the transformative process, which has to be defined from both a planning policy and infrastructure investment perspective. The latter aspect is outside the scope of this thesis, but the next section offers a scenario approach to the transformation of two areas of the Gold Coast, using the south-eastern quarter of the suburb of Labrador as an inner urban example and Coomera as a greenfield example. The grounded theories, integrated conceptual model and the model of the suburban scenarios at Figure 7.4 in section 7.3.4 are applied to the transect area in Figure 8.5 and to Coomera in Figure 8.9 to illustrate the inner and outer urban transformations for sustainable development suggested in section 7.4:

1. towards the 'transitional city of tomorrow'; and
2. towards the 'oil-constrained city of the future'.

8.3 Towards the transitional city of tomorrow

In section 4.2.5 the inner urban area of Labrador adjacent to the Southport CBD was selected to illustrate the urban transect and population density gradient concept, as one of the few city areas where it is evident. This section describes a scenario for transition of southeast Labrador in the mitigation and adaptive phases of oil depletion with rising transport costs. This area is chosen because it appears to be a good candidate for urban renewal as the Southport PDA is redeveloped (Figure 4.13). The urban transect is reproduced in **Figure 8.5** and matched to the population density gradient in **Figure 8.6**.

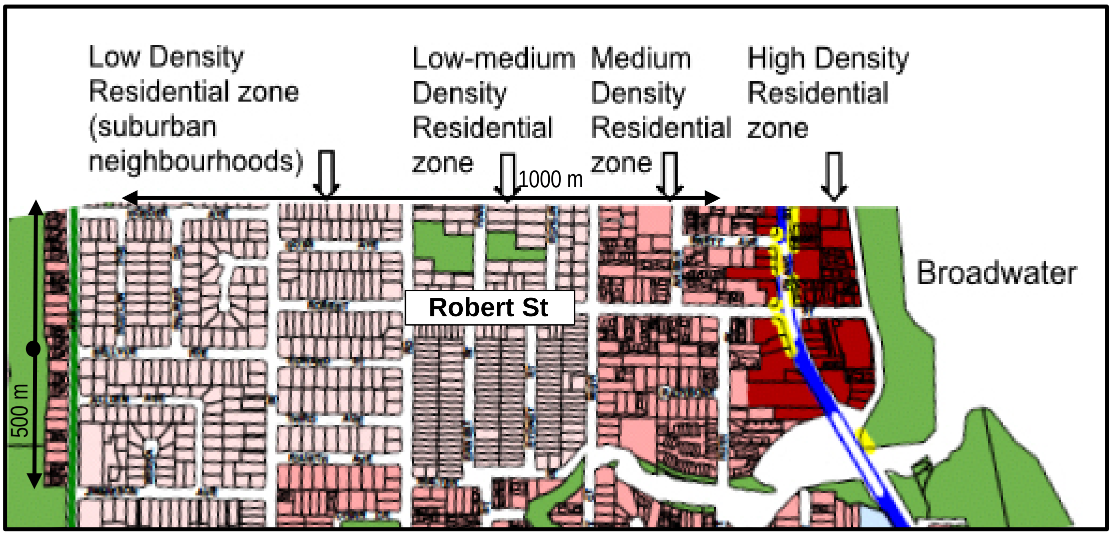

Figure 8.6: Typical discrete urban transect for Labrador, Gold Coast

Source: Modified Gold Coast draft planning scheme map 23 with permission (GCCC 2012)

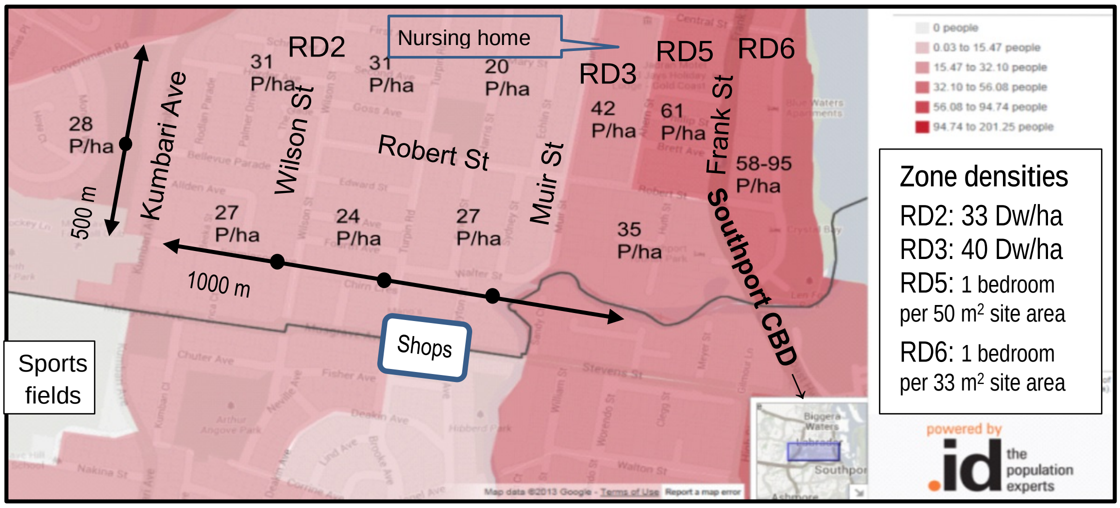

Figure 8.7: Labrador urban transect showing population density (persons/ha)

Source: modified from GCCC social atlas (Google 2013 base) (GCCC 2013b)

8.3.1 Labrador planning and development context

This southern part of the suburb has been gentrifying since the 1980s. Figure 8.7 shows the population density in persons per ha in 2011 for the transect area in Figure 8.6, to indicate the density gradient in the inner suburb, based on ABS census data. The High rise-high density area (RD6) towers at the Broadwater shore gradate towards townhouses and cottages in the west. The eastern area also has an aged nursing home and a caravan park that increase the net density; however, parks and the foreshore park distort the picture. Although the lot sizes are smaller towards the east, the actual density does not achieve even half of RD2 over the two lower density residential transect zones. The tower precinct fails to reach even RD5. So the area is less than half of the planned density, with an average occupancy rate of about 2.1 per dwelling. Yet the total population in the area of 90ha is about 2700 (~30 per ha), actually one of the highest small area densities in the whole city, and similar to Surfers Paradise at 32 persons/ha. Coincidentally these densities compare with the low rise historic Stamford UK gross town density of 24.7 persons per ha. The Gold Coast City council has consistently resisted changing the character of residential areas, requiring new development to be sympathetic to the existing fabric. Hence the new looks much like the old, even in areas with approved intensification, such as in the RD3 and RD5 zones in Figure 8.6, which helps to explain the under-development of Labrador and similar areas. The conclusion is that the area has not achieved the current planning strategy and would need council intervention to enable the development intensity to significantly increase.

Figure 8.8 provides a visual indication of the settlement pattern as an aerial view from Google Earth©. It shows medium-high rise along the Broadwater Marine Parade strip; low rise apartments and townhouses along Gold Coast Highway-Frank St (inset yellow line box); cottages on small lots gradating westward to larger lot cottages in a greener setting. Many old houses have asbestos issues. Regeneration has continued since this 2008 image, mainly on individual lots, which are the least risk or problematic for developers to acquire. The result is an evolving patchwork of ad hoc redevelopment that makes any comprehensive urban renewal strategy increasingly difficult to implement. The long term scenario without any intervention will likely be a fragmented built environment of dramatically different ages and condition that has some housing affordability benefits, but is redeveloped in an uncoordinated way.

Figure 8.8: Aerial view of Labrador urban transect looking northward

Source: Modified from Google Earth© imagery 2008

The current population only supports the public transport service, because it is on through-routes for several services. Three bus routes serve the locality with a distance of 600m between the central routes along Wilson and Muir Streets; which appears to be convenient for access, but the off peak frequency is only 60 minutes. In contrast, the eastern route along Frank St (Gold Coast Highway) has multiple high frequency services. The east–west bus routes are 2 km apart on the northern and southern boundaries of the suburb, beyond the view of Figure 8.7. Pedestrian access to the main commercial facilities in Frank Street is impeded by the block layout, relying on residential Robert St as the spine of the area. The distance from Kumbari Ave to Frank St is about 1.25 km, which is just beyond the suggested 1 km public-active mobility neighbourhood extent. However, small shops are located within the area and a local shopping centre (Chirn Park) is south in Musgrave Ave as shown in Figure 8.8. Chirn Park is the practical node for a neighbourhood extending from Central St to Smith St in the south. The conclusion is that there is significant potential and justification for densification into an urban village centred on the Chirn Park shopping centre as shown in **Figure 8.9**. Loder Creek acts as an internal barrier and effectively as a boundary; Smith St arterial road is a significant traffic barrier and Central St to a much lesser extent. Some blocks considered suitable for initial urban renewal within the Heydon Heights Labrador section are shown in orange outline. The concept scenario is discussed below.

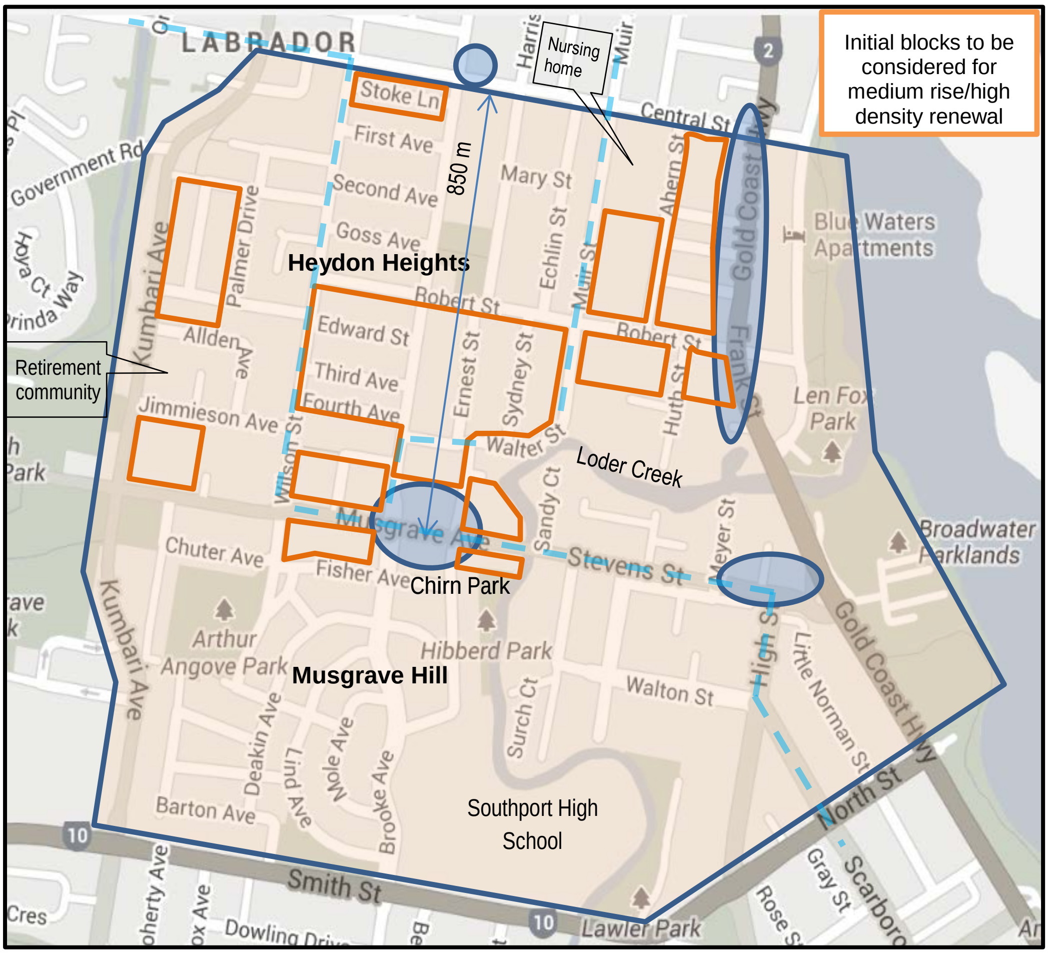

Figure 8.9: Heydon Heights-Musgrave Hill urban village

8.3.2 Demonstration scenario for oil depletion adaptation strategies

Figure 8.9 indicates a very significant, if not dramatic, change of planning strategy for the City of Gold Coast; one that could only be undertaken as a comprehensive local plan. The precedent is set with the declaration under the *Economic Development Act 2012* of the Southport Priority Development Area (PDA) in October 2013 to create the principal CBD for the city. An extension of the PDA to this area would be an opportunity for a test case to create an urban village close to the CBD. Figure 8.9 is a concept; a snapshot of a complex technical planning project that could only be achieved with state government direction as well as with full community engagement.

The justification for the Labrador PDA proposal is in it being one of a series of oil depletion adaptation strategies that offer real housing choice for residents to live close to the main CBD, rather than in greenfields Coomera and to address the demographic transformation. It would incorporate affordable housing in the mixed use precinct. The plan rectifies the underperformance of the past and current planning schemes that have failed to reach the density targets in what could be regarded as a greyfield suburb with inhibiting asbestos issues. It would implement the strategic framework policy to become a transit supportive urban neighbourhood that has not yet been achieved, despite the existing higher density zones in the Labrador area shown in Figure 8.7. The concept also aligns with the adjusted QPP3 for the 60 per cent infill dwelling target advocated in the SEQRP across inner suburbs and activity centres. This would be achieved by the PDA local plans around the Chirn Park activity centre and along the transport corridors, within form-based mixed use zones suggested in the *Bold Future* plan. A large inner urban population would give strong economic and workforce support to an expanding Southport CBD. The concept aligns with the Mayor's plan to make the city 'the most liveable, affordable and prosperous place in Australia' noted in section 8.1.1.

Grounded theory 2 and the community acceptance study reported in section 7.2.7 are applicable to the concept, in relation to the medium and high intensity housing expected in the draft planning scheme to occur within transit supportive urban neighbourhoods. While Figure 8.9 does not indicate building types, the form-based adaptive design for oil-constrained sustainable urban residential forms could be facilitated most efficiently by medium rise/high density apartment buildings. The form of such buildings should be responsive to the economic conditions, guided by the orientation and environmental factors. In the eastern section, perimeter blocks may be appropriate and would mutually reinforce a desirable urban streetscape to provide the pleasant shaded 'green' streets that are essential to an enlarged precinct. Aside from any urban design issues in achieving an attractive streetscape to gain the acceptance that occurs in the European model, community engagement is vital to address the resistance to higher density development relying on council supported or led site amalgamation projects. Site amalgamation in the PDA would be facilitated by legislative amendments under consideration by the state government to overcome frustrating tactics by greedy site owners. There is however an argument for a council role as an objective broker.

Of course there are many hurdles to overcome apart from the obvious NIMBY syndrome and landowner holdouts, including how to plan around heritage listed properties and new development. This concept is only one of several options to provide the balance 101,000 dwellings within the current urban footprint by 2031 after greenfield land supply was estimated to be exhausted by about 2017. The natural aging of both the local population and the housing can work to the advantage of the urban renewal program. However, the political reality is that a future greenfield community cannot vote a councillor out of office, but an assertive greyfield one certainly can do so. Hence all the benefits of facilitating inner urban living would need to weigh heavily, if not overwhelmingly, against the much easier option of expanding the urban footprint, with all its disadvantages and future mobility stress raised under grounded theory 3. This scenario represents the adaptive strategy suggested in the model in Figure 7.4. The alternative maladaptive scenario is that inner urban Labrador and similar greyfield areas would remain a low-intensity residential environment focused on retaining the existing patchwork character (GCCC 2012: Part 3: 36). It would point to the scenarios discussed in the next section for an oil-constrained city of the future.

8.4 Towards the oil-constrained city of the future

Under the *Bold Future* plan, the Coomera-Pimpama area is shown in **Figure 8.10** to be the largest city greenfield development area; promoted as a ‘transit supportive neighbourhood’ focused on the Coomera rail station and future Coomera town centre. The area has been developed beyond the original village area since the mid-1990s planning charette. Residential developers have built mainly detached housing estates, firstly at Upper Coomera on the western side of the M1 Motorway and more recently in the Coomera and Pimpama areas east of the Gold Coast railway. The town centre planning is approved as the third Principal Activity Centre in the city, and is starting construction at the time of completing this research. It is focused on the rail station as the main transit element in the strategic plan. The strategic plan extract in Figure 8.9 shows the district straddles the M1 and railway—effectively creating separate entities bounded by the hills to the west, sugarcane farmland and wetlands to the east, Pimpama Creek and the inter-urban break to the north, and Coomera River to the south. This area was to house some 80,000, but that target has been revised downwards as densities fail to reach the intended minimum 15 dwellings per ha. The western side is now substantially developed. The east side is the last greenfield land for urban growth, yet strangely the draft strategic framework is silent on this community (GCCC 2012: Part 3).

This section uses the planning device of alternative scenarios to apply the grounded theories, integrated conceptual model and the model of the suburban scenarios in Figure 7.4 to the eastern Coomera-Pimpama district in Figure 8.10. The transformation scenarios illustrate contrasting futures in the adaptive phase of oil constraints in the grounded theory statements in the section 7.4 introduction. The first is maladaptive and the second has a sustainable outcome for Coomera and, by extension, all the city.

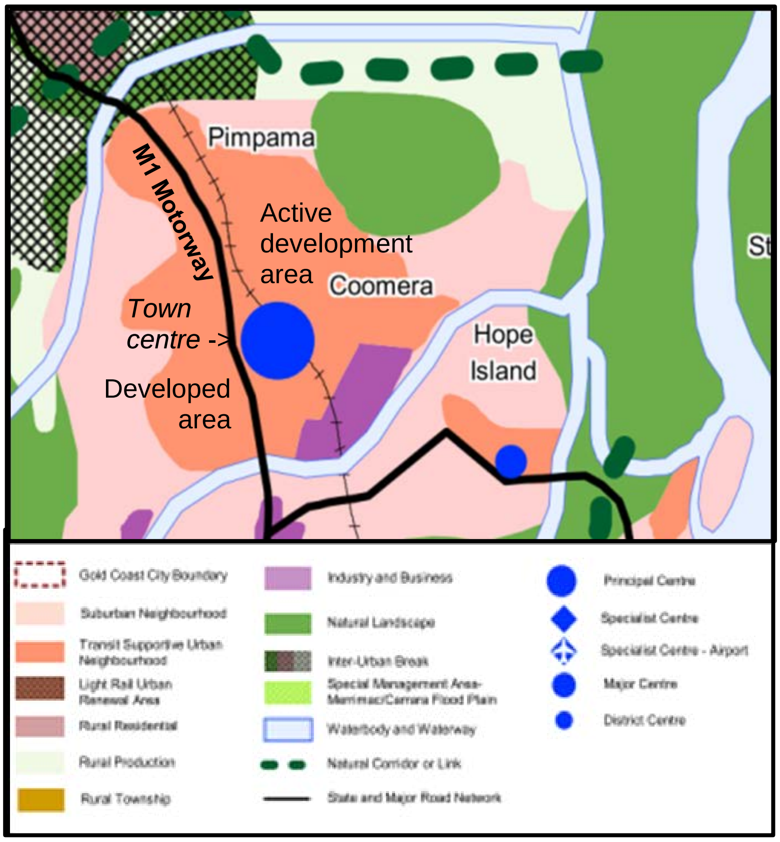

Figure 8.10: Coomera district strategic plan extract

Source: Gold Coast City Council (with permission)

8.4.1 Coomera scenarios for oil depletion adaptation strategies

In 2012 the Coomera-Pimpama district had a population of 12,310 in an area of 6,600 ha. The population density was 1.86 per ha, because of the large tracts of undeveloped land and wetland, but actual occupancy rates in the mainly detached housing estates averaged 3.0 (Appendix C). The dwelling statistics are displayed in **Table 8.1**.

Table 8.1: 2011 Coomera-Pimpama dwelling statistics 2006-2011

Coomera-Pimpama	2011			2006			Change
Dwelling type	**Number**	**%**	**Gold Coast City**	**Number**	**%**	**Gold Coast City**	**2006 to 2011**
Separate house	3,282	71.9	55.8	1,406	63.9	54.0	+1,876
Medium density	1,277	28.0	24.5	712	32.3	23.7	+565
High density	0	0.0	18.1	0	0.0	20.4	0
Caravans, cabin, houseboat	0	0.0	1.3	78	3.5	1.5	-78
Other	8	0.2	0.2	6	0.3	0.2	+2
Not stated	0	0.0	0.1	0	0.0	0.1	0
Total Private Dwellings	**4,567**	**100.0**	**100.0**	**2,202**	**100.0**	**100.0**	**+2,365**

Source: Gold Coast City Council community profile (2013b).
Based on Australian Bureau of Statistics census data for 2006 and 2011

The future development of the Coomera-Pimpama greenfield area is guided by the strategic foundations and detailed provisions set out in the existing planning scheme, the Coomera Local Area Plan and Town Centre Structure Plan, and any new directions arising from the new *Bold Future* scheme. None of the existing plans take into account even the possibility of oil depletion. However, the draft strategic framework does make a single mention of 'peak oil' in relation to 'a network of mixed use neighbourhood centres [that] occur within Suburban and transit supportive urban neighbourhoods and provide a range of goods and services to satisfy day-to-day convenience needs' (GCCC 2012: Part 3: 31). In this context only—i.e. no broad consideration of future oil constraints:

> Neighbourhood centres of a size that exceed the needs of its defined immediate neighbourhood are avoided, or not expanded to maintain opportunities for future neighbourhood centres to emerge in a framework that encourages active transport and improves the city's resilience to the effects of *peak oil*. [Italics added]

A bold future is certainly required if a significant proportion of the 40 per cent of additional 101,000 new dwellings (at the current occupancy rate of 3) noted in section 8.1.1 are to be located in the balance of the Coomera greenfields. Some 30,000 dwellings at the intended minimum 15 per net ha would require the order of 3,000 gross ha—which is half the total development area—and does not factor in other uses. Moreover, only a fraction of the total 6,600 ha is actually available because of environmental constraints and the draft plan cautions that the greenfield land supply could be absorbed by 2017. In addition, this development only caters for the estimated growth to 2031; and would need to develop at triple the current rates of 2400 dwellings in five years. Beyond that period lies a fog of uncertainty. So let's look back on Coomera nominally from 2042.

8.4.2 A maladapted future scenario

The 2041 census results have been released. They confirm the worst estimates made by Gold Coast City Council planners that the oil adaptation strategies have failed. It was hoped that the concerted efforts to densify the city since the disheartening results in 2031 and again in the 2036 census would have had a greater effect on the property development and marketing sectors. However, with the greenfield land used up in low density housing estates, the expanding urban footprint strategy has, like constructing more motorways in the 2010s, simply filled up each new area with more urban sprawl.

The great hope of densifying the Coomera-Pimpama district failed to eventuate beyond the Coomera Town Centre to any significant extent. The seeds of failure were sown in the earlier decades of the century in allowing single storey houses to blanket the woodland-turned-'greenfields' for another decade after the *Bold Future* planning scheme in 2014. What should have been mandated minimum densities with a larger mix of alternative accommodation failed to be approved under pressure of the so-called 'market forces', so the minimums remained maximum standards into the 2020s. Although the signs of peak oil were plain to see, lack of leadership and procrastination at all levels of government dragged on, while the oil adaptation and energy descent strategies advocated by experts and groups associated with the Association for the

Study of Peak Oil and Gas were largely ignored. The false hopes of technology blinded the policy makers in the same way that climate change was also ignored, until too late.

The early decades Coomera housing could not simply be demolished; repeating the same dilemma of renewing the greyfield inner and middle suburbs around Southport CBD and Robina Town Centre against the collective resistance of residents and politicians alike. No—that land would be off limits for another two decades until the 2060s at the end of their economic life cycle. At least those houses will be easier to demolish and recycle, unlike the asbestos riddled mid-1900s housing in Labrador and the coastal areas. And the growing commitment to solar PV to complement the gas-fired base load power stations has reduced stationary energy costs. Meanwhile the rising cost of petrol and petrochemical materials has affected the whole housing industry and caused further affordability stress on top of the cost of operating private cars out in the suburbs. Most of the council staff have moved close to their offices and use shared council electric cars or Segways. The snowball effect has forced a rethink in the council about urban renewal, but the added costs of demolition and construction of new housing also affect the affordability of inner urban apartments. In the 2030s the state government amended the planning legislation to facilitate comprehensive renewal and even subsidised residents suffering housing poverty into manufactured homes as an interim measure. Most of those families are still there in a strange cultural shift to a more communal lifestyle. The cohousing communities are thriving in popularity.

It has been a fascinating social phenomenon to see how people across the whole demographic spectrum have been forced to become more resourceful and cooperative with the accelerating oil constraints. If only national governments could emulate them, we could be sharing instead of fighting over the precious oil reserves. But back to Coomera, we are belatedly learning the lessons in how an urban village actually works and how we can regain the horticultural skills our parents never taught us. Whoever would have thought that the 2040s are an echo of the wartime 1940s with widespread rationing and such hardship? A group of our planners has just returned from an arduous study tour travelling by sea to the old European cities. Some of those sustainable cities are thriving economically and the oil crisis has not become the looming catastrophe that we are facing. The take home message of the study tour was that the inherent resilience of both the urban fabric and the community has enabled a relatively painless transformation into ecologically and socially regenerative ecocities. Is that what sustainability is all about—a healthy, peaceful, painless life?

8.4.3 An adaptive transformed future scenario

In contrast to the potential 'Mad Max' syndrome that gave us planning nightmares of an oil-starved catastrophic future, the council rallied the community to embrace the *Bold Futures* planning scheme wholeheartedly[31]. The year 2014 was such a momentous,

[31] The draft *Bold Futures* planning scheme has become the 2016 *City Plan*, yet similar principles apply.

yet scary turning point for the city and for Coomera, we wondered if it would be like one of those wild rollercoaster rides at a Coomera theme park. Well it was for a few years, as the community slowly came to accept the implications of peak oil—despite the mocking derision of our northern neighbours, locked into their roads and tunnels.

The grand plan was to reset the compass on how the mayor's vision of 'the most liveable, affordable and prosperous place in Australia' might be translated into the look and functioning of such a lifestyle and tourist oriented city—the flamboyant Gold Coast. It was a case of relearning about sustainability and resilience, especially with accelerating climate change and severe weather. Fortunately the transition towns movement was active in the city. Looking back from 2042 with the results of the 2041 census, the effort has been worthwhile and the city is barely recognisable beyond the towers of Surfers Paradise and the coastal strip. Many tourists have gone, but the high rise apartments are full of owner occupiers. The investment in the green economy and renewable energy has repaid the community with far more and better employment to replace the low paid hospitality jobs. We still have lots of home grown hospitality in the cooperation between neighbours and in the sharing of making useful things to substitute for oil-based petrochemicals. The Coomera theme parks have survived and become cultural centres of learning new skills and enjoying a life of lower technology.

Coomera itself is a city rather than a suburb, which is a story that has made national headlines as well as earning planning awards for excellence. The Town Centre just kept on growing up and out to engulf its surroundings. The rail line was buried so it was no longer a barrier to movement, or a noise source. The Dreamworld theme park architecture inspired developers to take on a radically different European, almost Parisian, inspired theme starting with the Coomera Urban Village master plan approved back in 2012 (GCCC meeting minute 13 December 2012: 659). That was the catalyst for a transformation, not only in Coomera, but also in Southport, where the 2013 declaration of the priority development area revved up the light rail corridor renewal and the 2018 Commonwealth Games facilities architectural design. The Coomera Urban Village was exciting interest in urban design trends and different urban forms, because people could see and experience a home grown product that actually worked as an urbane village and rivalled West End in Brisbane, with both aesthetic and technological imagination. Its 6 storey perimeter blocks and 10 storey towers echoed the 1970-1990s imagination that recreated Surfers Paradise as a dense, vibrant tourist landmark. Southport was the next success story.

Over the 2020s decade, the inner urban communities around Southport took up the challenge to share their space and envious lifestyle with the growing population wanting to live close to the new employment opportunities in the CBD. Such a social transformation could not have succeeded without the informed and creative leadership of the elected council and the professional knowledge of the staff in a holistic approach to sustainable development. The threat of future oil constraints was not so much a negative driving force, as a catalyst to become a regenerative city. The inner urban renewal took the land development pressure off areas such as Coomera and saved costs in engineering infrastructure. The benefits in enhanced mobility and in more efficient building construction made a more affordable lifestyle possible. The trade-off between mobility and personalised transport was a generational paradigm shift as millennial parents let go the aspiration to own a car that stayed in a garage.

The car alternative was to share what transport was needed and embrace the digital communication revolution started by the smart phones of the 2000s. These devices now control the home as well as the home life. They have also opened windows into the world—to other ways of living a less materialistic existence as everything associated with oil becomes more expensive or unavailable. A suburban house could be interchangeable with an urban home, built with clever design and overcoming suburban isolation, or with a cohousing complex combining privacy and community. A life without oil could be contemplated calmly as a viable alternative; just as city living could be contemplated as a viable network of places for peaceful meditation or social interaction with others. Public transport has made the city fully accessible with diversified forms of vehicles—from mainline trams to small solar powered pods up above the main streets. However, the objective has been to reduce the need for commuting by close integration of the home-work-education-recreation-shopping built and green environment. That was a challenge in persuading people to consider swapping homes rather than rebuilding, until the 2030s oil crunch made the idea popular. Elderly people became more receptive to reshaping their house for sharing, which eased the housing burden on poorer residents and the need for more building. This arrangement also benefitted the elderly to age in a familiar place and eased the burden on aged care facilities. The scheme made living more affordable for everyone.

There were some downsides in the transformation to an oil-constrained city in the 2030s, which will no doubt be exacerbated in the future. Tourism became increasingly problematic as international airfares skyrocketed and airlines contracted services. So the former main economic driver in the city made a painful withdrawal from its dominant position. Small domestic scale builders were forced to find new skills in commercial scale operations, or focused on renovations and maintenance. Travel to job sites became more expensive, then more difficult, unless public transport could be used. Most of the tradespeople invested in gas or electric vehicles to maintain mobility, but diesel powered heavy construction machinery was exchanged for lightweight models that adapted to using lighter materials and less site excavation or recontouring. This was easier in inner urban renewal projects requiring less engineering work. The use of concrete was reduced by alternatives such as geo-polymers and structural timber. The latter will be more feasible when the first native plantation hardwood trees come to maturity. The more severe weather and flooding in the last two decades have caused a rethink about concrete slab on ground construction and most apartments have sacrificial ground floor parking rather than basements. Fewer cars, rapid growth of car sharing schemes and the community based ride sharing services have reduced the garaging demand in any case, which has also reduced building construction and costs. Driverless cars are also becoming prevalent.

In summary the last two decades have set the Gold Coast on a new pathway to a sustainable future looking beyond the oil-based economy. The initial transition forced courageous political decisions to be made about the desirable urban form of both the inner urban and outer suburban areas. Having embarked on this journey, there was no turning back, just as we were sure that oil constraints are inevitable and had to take the community on the same difficult path of awareness and transformation. The results of the 2041 census confirm the extent of the urban paradigm shifts: in where people live; the higher residential densities and occupancy rates; less work related travel and much more active modes of mobility; less energy and water usage. People seem to be more active and healthy, have more disposable income and less housing stress. Volunteering is increasing in every field and the happiness index is better. It took a rational acknowledgment that oil is a declining resource, and a concerted effort by all levels of government and an engaged community to bring about these changes. There will be future transitional issues to resolve at the city and regional levels, such as food security and the transition away from coal seam gas as it declines. They are intimately connected in food transport and the transition away from industrialised agriculture and fertilisers. Thankfully we now have a horticultural industry in the former city canelands and fish stocks are improving, although fuel is still problematic. The positive take home message is that we have learnt from the wise and acted early. The combination of changes has made this city resilient to these and other challenges.

8.5 Conclusions on the oil-constrained city

This chapter has addressed research objective 3.3 by applying the grounded theory and models about sustainable residential development in an oil-constrained future derived in Chapter 7 to the City of Gold Coast. The grounded theories and the integrated conceptual framework could guide the strategic direction of the future planning of the city for housing in accordance with the amended State Planning Policy to meet the diverse and changing needs of different communities; facilitating consolidation of urban development in the city; and providing for best-practice, innovative and adaptable housing and urban design that promote attractive, adaptable and accessible built environments. The suggested inner urban renewal would contribute to compact form and consolidation within the existing urban footprint to limit urban sprawl and therefore future mobility stress. In the redevelopment of the inner areas, medium rise/ high density apartment buildings in perimeter blocks, or high rise towers above podiums would achieve the stated SPP objectives in the most efficient urban form.

While the urban form is not at all like the old European cities and there would appear to be no compelling reason to emulate those energy efficient cities, the decision to make Southport the Gold Coast CBD is a turning point. The proposed character of development in the CBD residential precinct 2 (Figure 4.13 in section 4.3.3) is to be ‘perimeter block or iconic high rise towers set above a podium’ in a ‘highly urbanised environment that is activated at ground level by design and use’ (DSDIP 2013e: 25). Perimeter blocks as in the studied European cities are the preferred adaptive design in grounded theory No. 2 for oil-constrained sustainable urban residential forms. If the Southport PDA planning intent were to be even partially implemented with perimeter blocks, it would provide a valuable demonstration site to validate application of the grounded theories. The high rise podium form is common in Surfers Paradise area of the Gold Coast and emulates sustainable cities such as downtown Vancouver.

The draft *Bold Future Planning Scheme* has been withdrawn to develop a new style planning scheme as being a people’s *City Plan* to make the city ‘the most liveable, affordable and prosperous place in Australia’ (Mayor Tate, media release, 5 September 2012). Nevertheless the draft plan has been available and is a useful guide to the new plan. The planning hiatus is an opportunity for the council to release the oil vulnerability strategy and incorporate it into the new scheme. The major challenges noted in section 8.1.1 are considered to increase under conditions of declining oil supply. The forecast is to construct the order of 101,000 new dwellings by 2031. The developer led suburban expansion of low density housing generally northwards through the Coomera district (Figure 8.9) is slow to meet the challenges of changing demography towards an older population and lone-person households. New development in Coomera is intended to be developed as suburban and transit supportive urban neighbourhoods around the Coomera Town Centre. Grounded theory 3 suggests redevelopment pressure will accelerate in inner urban serviced areas close to public transport. The urban renewal process in the aging greyfield suburbs developed in the mid-1900s, such as Labrador near the Southport CBD, exacerbates resident resistance to higher density developer led site amalgamation.

The suggested planning responses demonstrate some ways in which the local Gold Coast planning scheme strategically could facilitate the transformation to the future taking into account the grounded theories and the integrated conceptual framework. An overview of well-known planning models in section 8.2 illustrates some of the planning tools relevant to achieving oil-constrained sustainable urban residential forms, as established in the conceptual framework. The models include cohousing, new urbanism and smart growth, transit oriented development, urban villages, regenerative ecocities concepts, and transition towns initiatives. These alternative urban patterns have all been advanced as being more sustainable in relation to climate change, enhanced liveability, resource conservation and increased transport efficiencies. Cohousing communities fit flexibly into all the patterns.

Section 8.3 suggests a scenario approach to apply the grounded theories, integrated conceptual model and the suburban scenarios model at Figure 7.4 in section 7.3.4 in two phases to the south-eastern quarter of Labrador as an inner urban example in Figures 8.5 – 8.9; and to the Coomera-Pimpama district as an outer greenfield suburb example in Figure 8.10. The case studies have wide application to other western cities.

Towards the transitional city of tomorrow *(section 8.3)*

The Labrador area is chosen because it appears to be a good candidate for urban renewal as the Southport PDA is redeveloped. The suburb has been gentrifying since the 1980s, however, the result is an evolving patchwork of redevelopment that is less than half of the planned density and has not achieved even the current planning strategy. Nevertheless significant potential and justification exists for densification into an urban village centred on the Chirn Park local shopping centre as shown in Figure 8.9. The strategy of declaring a PDA would be necessary for a demonstration case to create an urban village as an oil depletion adaptation strategy. It offers real housing choice for residents to live close to the CBD rather than in greenfields Coomera, regardless of the future. The alternative maladaptive scenario is that inner urban Labrador and similar greyfield areas would remain a low-intensity residential environment focused on retaining the existing patchwork character (GCCC 2012: Part 3: 36). It would point to the alternative scenarios discussed in section 8.4 for an oil-constrained city of the future.

Towards the oil-constrained city of the future *(section 8.4)*

The Coomera-Pimpama area shown in Figure 8.10 is the largest greenfield development area in the city urban footprint, promoted as a transit supportive neighbourhood. The planning device of alternative scenarios looking back from 2042 illustrates contrasting futures in the second adaptive phase of oil constraints of Figure 7.4 in section 7.3.4. The maladapted scenario portrays some possible effects of continuing the business as usual low intensity development in Coomera that ignores the oil adaptation and energy descent strategies until too late.

In the adaptive transformed future scenario, the council rallies the community to embrace the *Bold Futures* planning scheme planning principles and policies, accept the implications of peak oil as a catalyst to become a transformed regenerative city, and resets the compass on how the mayor's vision might be translated into the look and functioning of such a lifestyle and tourist oriented city. Coomera becomes a city rather than a suburb; Southport urban villages copy the success of the first Coomera Urban Village. The city becomes resilient to change on a new pathway to a sustainable future, looking beyond the oil-based economy.

The scenario planning method uses a creative envisioning narrative to highlight alternative local government led responses to the serious planning issues that are at the heart of this thesis research. The state-wide planning system sets the overall framework, but local communities, led by innovative and farsighted local governments, have the opportunity and the means to follow an alternative pathway to a transformed sustainable and regenerative urban future.

Chapter 8 has demonstrated the contribution of the grounded theory and models of sustainable development to the thesis by application to the reference City of Gold Coast. The thesis contends that such an adaptive strategy is an effective way to transition western cities like the Gold Coast to an oil-constrained future.

Chapter 9

Conclusion: towards the oil-constrained city

This chapter culminates the research journey in search of the sustainable city in an oil-constrained future—the oil-constrained city*.* The following sections draw together the research about the dependency of urban residential development on oil and present the research findings. The contributions of the thesis to sustainable development planning theory and practice are affirmed. The final sections evaluate the thesis goals and research methodologies, and make suggestions for further research relating to the central problem, which is stated as:

> **Possible future oil constraints may affect urban residential development and hence the planning of sustainable urban forms in the context of a twentieth century Australian coastal city.**

9.1 Findings of the research

This section presents the findings of the mixed methods documentary and empirical research, and the applied grounded theory development in relation to the research objectives. The thesis derives a conceptual framework from urban metabolism theory to examine the oil-related and planning-related inputs to urban residential development, which informs a grounded theory approach that links the framework to sustainable urban design and urban morphology.

The Australian City of Gold Coast in South East Queensland is selected in Chapter 2 as a reference city for the research, including: land use planning policy opportunities and barriers; application to four pilot case studies of a representative residential typology; and demonstrating the grounded theory and models with a scenario method.

9.1.1 Part 1 research findings

Part 1 investigated the first research question:

> *In the context of the growth of major Australian cities, what are the relationships between urban residential forms in the oil-based economy, and a future with constrained global oil supply?*

This question was pursued through three research objectives and the key findings are set out below.

Research objectives 1.1 and 1.2 - Chapter 2

1.1 *Understand the context of Australian urban forms in the oil-based economy, including urban morphology and design, and sustainable city concepts.*

1.2 *identify how oil-related issues are being addressed in urban growth management of major Australian cities, beyond the current climate change oriented responses.*

The exploratory literature review in Chapter 2 finds that in the Australian context:

1. Low density suburban characteristics of major cities have been supported by expansionary planning policies, with oil dependency directly contributing to urban sprawl.
2. Future oil depletion is directly linked to sustainability by the change process in adapting future urban design in terms of building types, density and structure.
3. The potential impacts of oil constraints on construction—and thus on the urban fabric—are found to primarily affect urban design at the lot and precinct scales, which may then be reflected in the changing morphology of urban form.
4. Analysis of the concepts of urban design, sustainability and resilience confirms that the related concept of transformation of urban form towards an oil-constrained future is an appropriate framework to use in this research.
5. Three recent growth management plans for Perth, Melbourne and South East Queensland—including the reference City of Gold Coast—emphasise that pursuing suburban sprawl will be unsustainable, partly because of oil dependent general transportation. The studies advocate planning responses to climate change, and in that context, promote public transport and reduce greenhouse gas emissions from transportation.
6. The strategic planning scenarios assume a continuing business as usual approach to constructing urban infrastructure and the necessary facilities to support urban living, which disregards future oil depletion.
7. While a land use planning shift towards higher density forms is advocated, the practice of greenfield residential development is a barrier to change from the traditional detached single storey dwelling model, beyond inner city areas.

The findings on objectives 1.1 and 1.2 establish the relationship of oil dependency to urban residential development, particularly relevant to future urban growth in major Australian cities, reinforcing existing concerns for sustainable urban form.

The overall findings point to a key proposition that:

Relationships between urban residential development in the Australian context and oil dependency exist and may be significant in the growth of major cities.

The significance aspect of the established relationships in the context of Australian major cities was investigated through research objective 1.3.

Research objective 1.3 - Chapter 3

1.3 Investigate the oil dependency relationships in urban development in the context of sustainability concepts, by reference to material and energy inputs.

The investigations in Chapter 3 into the significance of oil dependency find that:

8. The complexities of the economic, social and environmental consequences of oil dependency extend well beyond the urban development conclusions in Chapter 2 into every facet of modern society and technology as an emerging *global wicked problem*. It will also be a *social mess*: composed of inter-related dilemmas, issues, and other problems at multiple levels of society, economy, and governance.

9. Since the global peak of conventional oil production in about 2006, a six per cent decline rate in existing fields is confirmed by the International Energy Agency that forecasts the global conventional oil supply to be halved by 2035 without massive new oil finds on a scale that has not been seen since the 1980s. The optimistic USA forecasts about replacement by unconventional tight oil will not suffice.
10. This finding reinforces a proposition that the transition towards an oil-constrained future is predicted within the current strategic planning horizon.
11. The urban metabolism theory used to develop the initial conceptual framework is confirmed as an appropriate method using material flow (life cycle) analysis to identify the oil and gas inputs into urban development.
12. The analysis demonstrates the extent of the oil dependency in the manufacture of most building materials, either as a feed stock, embodied energy input, or transport input; and notes that 'oil will make up approximately 32% of energy use in building materials and construction as far into the future as 2055' (AGO 2006: 71).
13. Review of planning literature in the 2000s, Australian policy research papers, and local government planning strategies reveals an increasing awareness about oil supply vulnerability and beneficial impacts on the climate change.
14. A comparison of oil depletion and climate change mitigation and adaptation in section 3.2.2 proposes a new set of terminology for oil depletion; and a case study suggests that prioritising adaptation strategies is more effective in the longer term. **The analysis is offered as a contribution to extending planning theory**.

The analysis concludes that constraints on oil supply will have significant impacts for all types of urban development. The Part 1 propositions modified in Chapter 3, that the oil dependency relationship may be significant, are considered to be strongly supported:

> **Significant relationships exist between new urban residential development and oil supply constraints in the growth of major cities in the Australian context, with respect to land development, building construction and ancillary transport aspects that affect all stages of such processes; requiring oil depletion adaptation strategies.**

9.1.2 Part 2 research findings

The relationships identified in Part 1 were investigated in relation to the Part 2 research question in the context of the selected reference Australian City of Gold Coast:

> *How might the land development and building construction factors and the land use planning framework factors influence urban residential forms in the context of a selected Australian city?*

The question was pursued through two research objectives with the following findings.

Research objective 2.1 - Chapter 4

2.1 Identify the oil-related and planning-related factors that may affect the development and construction processes applicable to residential development.

15. The analysis of the oil and gas related inputs in land development, building construction and transport energy establishes the relevance to the proposition of the main alternative natural materials and renewable sources of energy, along with energy efficient systems, which act as intervening factors in all development.
16. In terms of the mitigation and adaptation terminology proposed in finding (14), alternative building materials and construction techniques have adaptive effects that could potentially increase the resilience of all settlements to oil constraints.
17. The state land use planning regulatory framework factors influence urban residential forms to control urban development in a contingent way and therefore modify the application of the sustainable urban planning concepts in finding (4).
18. Recent amendments to the national Building Code of Australia require residential development after 2010 to be more responsive to conservation of embodied and operational energy, thereby reducing oil and gas inputs to meet rising energy efficiency standards. While this contributes to reducing energy demand, it may not lead to broader sustainable outcomes in the transition to an oil-constrained future.
19. In the City of Gold Coast context, the draft Gold Coast *Bold Future* strategic framework espouses the Next Generation Planning principles, which also inform the adopted *City Plan* (see footnote 21 on page 134). However, the thesis finds that the strategic residential objectives are aspirational goals, which would require detailed planning in both existing suburbs and newly developing communities to adapt residential development to an oil-constrained future.
20. The analysis of current planning guidance confirms the finding (7) barriers to promoting a transition from the predominant detached housing model in most greenfield suburban development areas towards a compact urban form.

The development oriented planning reforms initiated by the LNP Queensland government elected in 2012 departed from the sustainability objectives of the *Sustainable Planning Act* 2009, to prefer a state growth and prosperity agenda. The return of an ALP government in 2015 partly arrested that trend by reinserting sustainability and climate change objectives into draft planning legislation, as noted in section 4.3. The reforms were ongoing in late 2015 after this research was finished.

Research objective 2.2 – Chapter 5

2.2 Analyse the development and construction processes for a representative range of residential building typology to indicate the extent of vulnerability (if any) to future oil supply constraints.

Chapter 5 draws together the oil-related inputs stream and the planning and design stream of the initial conceptual framework into four pilot case studies of representative residential typologies in the City of Gold Coast. The case analyses to quantify the oil-related inputs have yielded interesting and valid findings, summarised in a comparison of embodied energy per unit area (GJ per m^2) across the four cases and indexed to a single storey four bedroom house, as illustrated in Figures 5.2, 5.16 and 5.17.

21. The embodied energy intensity (per m^2) is least for the steel-reinforced concrete medium rise six storeys apartment building with one basement parking level (Figure 5.16).
22. The embodied energy intensity of the selected dwelling unit types is compared on a more relevant per-bedroom and per-occupant basis (Figure 5.17). The results show that the detached house has least embodied energy on both these measures. The six storey apartment building is the next most efficient case with about 65 per cent more embodied energy than the house on an indexed comparison.
23. The cross-case analysis points to a tentative proposition that the medium rise-high density building type is the preferred compromise for a more intense form of development offering house-size apartments and sustainability and urban design factors relevant to the transition to an oil-constrained future.
24. There are of course many other sustainability factors to consider. Differences in living space—e.g. private external or outdoor areas, building footprint shape and orientation—all potentially affect energy efficiencies and liveability, and thus the public acceptance of a particular building form.
25. All the cases depend completely on road transport for materials, components and labour, which is the largest direct oil-related input based on a cradle-to-site analysis. The road transport and construction plant all rely on the oil economy.

While the case study is limited to four building types, the focused interviews also reinforce the lower energy and other amenity advantages of the six storey building type, which are reflected in the old European cities comprising an urban form featuring medium rise/high density perimeter blocks. The empirical facts and findings of the Part 2 research components give strong support to the Part 1 propositions in confirming the significance of the oil dependency relationship. The research meets the requirement of objective 2.2 and provides inferences and constructs, with which to develop theoretical concepts and models into grounded theory in Part 3.

9.1.3 Part 3 research findings

Part 3 investigated the third research question and its three linked objectives:

> *How might land use planning assist the transformation of urban residential forms in the selected Australian city towards an oil-constrained future?*

Establishing the significance of the oil dependency relationship in Chapters 3 – 5 marks a change in approach to pursuing the third research question, using a grounded theory investigative method. The reasoning to use this method to address Objective 3.1 is partly due to the nature of oil depletion as a global problem being viewed from the plateau of peak oil production, without historical precedent except for the short-lived 1973 oil crisis. The fracking of tight oil on a global scale, and growing opposition to it, also makes the future of oil supply highly uncertain and highlights the technical and political aspects of oil supply as a global wicked problem. The research looks back to the nineteenth century European cities of the pre-oil economy for guidance.

Research objective 3.1 - Chapter 6

3.1 Suggest relevant planning-related qualities and characteristics for oil-constrained cities, by drawing on values of pre-oil economy cities and experience of selected modern cities within a wider context of sustainable urban design.

The abductive method in Chapter 6 examines the design of urban residential forms, mobility and other relevant sustainable values of European pre-oil economy cities and the experience of modern cities. The coding of observations and data about these cities abstracts the concepts into themes relevant to the general planning domain, and ranked for three scenarios of increasing oil depletion. The grounded theory process suggests the following findings for an oil-constrained sustainable city.

26. The grounded theory core phenomenon expressed as *sustainable urban form* is a combination of urban structural units—as precincts of urban morphology and urban fabric design—that are influenced by the urban metabolism in the context of scenario C as oil depletion accelerates. The mobility and movement hierarchies are related in this thesis to public-active and mobility oriented development (P-AMOD) described in section 4.2.4 of Chapter 4 and applied in Chapters 7 and 8.
27. The qualities of sustainable cities are framed around three questions relating to: how the urban fabric might reduce dependence on oil; an efficient urban metabolism; and providing suitable housing and facilitating mobility of people and transport of food and goods to sustain the socio-economic functionality.
28. Ten derived planning-related characteristics of an oil-constrained sustainable city, plus an overlay of five energy and socio-economic related qualities, suggest theoretical propositions arising from the grounded theory analysis that are verified and distilled into four explanatory hypotheses for objective 3.2. The grounded theory coding also derives a compressed set of 27 relationships that validate the definition of sustainable urban form, although unsustainable forms are possible.

The comprehensive definition of urban form is offered as a contribution of the thesis to urban morphology to describe the character of an urban area.

It is slightly modified by the grounded theory coding to align with the properties of the urban form phenomenon (which might be more-or-less sustainable). In this thesis:

Sustainable urban form is a set of complex relationships comprising:

a. the pattern of urban structural units in a hierarchy of scales, transformed within the emerging historical, geographical, ecological and climatic contexts
b. the urban design —shape, height, density and appearance—of the built environment, including the interface between the built environment and public realm—streets and public spaces, public and private open greenspace
c. the mobility and movement hierarchies—networks and transport systems
d. the urban metabolism—supporting, facilitating and sustaining the socio-economic functionality of a city—including social and cultural processes, metabolic flows of substances, goods, energy and communication within a regenerative ecological footprint.

Research objective 3.2 - Chapter 7

3.2 Develop theoretical concepts and models about sustainable residential development in an oil-constrained future in the Australian urban context.

Four explanatory hypotheses derived in Chapter 6 are developed in Chapter 7 as grounded theory about sustainable residential development in an oil-constrained future, which are verified through focused interviews with key informants. The theories operate at different scales of the urban form and acknowledge a timing sequence in their relevance and application. This suggests categorising strategic planning in three phases: a mitigation phase of conserving oil supply and reducing demand; a '*transitional* city of tomorrow'; and ultimately towards an '*oil-constrained* city of the future'.

The four refined grounded theories are offered as original thesis contributions to sustainable planning theory in relation to the research problem:

Grounded theory 1:

Oil constraints will gradually affect all types of urban residential buildings at the site scale:

> Oil supply constraints potentially affect the sustainability of all new land development and construction of all types of urban residential buildings to varying extents, depending on the materials used and transport-related factors. Materials-related vulnerability may be reduced by adaptation to non-petroleum substitutes. Transport-related vulnerability may be reduced by conversion of diesel powered construction vehicles and machinery to available replacement 'fuels' as a mitigation strategy in the short–medium transitional phase.

Grounded theory 2:

Adaptive design is needed for sustainable urban residential forms at the precinct scale:

> Adaptive design for oil-constrained sustainable urban residential forms at the precinct scale of urban structural units is facilitated most efficiently by medium rise/high density apartment buildings arranged as perimeter/courtyard blocks; in relation to achieving objectives for building material and energy flows, urban density, adaptable functionality, streetscape and public-active mobility oriented development.

Grounded theory 3:

Oil depletion will increasingly affect urban communities at middle-outer city scales:

> The transport-related mitigation phase of oil depletion will increasingly inhibit suburban sprawl led city-wide expansion and accelerate redevelopment pressure in inner urban serviced areas close to public transport. In the later adaptive phase, availability of system-wide alternative energy powered vehicles may mitigate mobility and living cost issues in more affordable housing in existing middle/outer suburbs, as suggested in the suburban transition model in Figure 7.4.

Grounded theory 4:

Transformative planning system policies are needed at city-wide and regional scales:

> As the phenomenon of oil depletion gains international acceptance as a wicked global problem, it will influence government urban land use policies at both city-wide and regional scales within the Queensland and Australian planning system context. Transformative guidance on urban metabolic energy flows is linked to state and national policies on transport, renewable energy and climate change

mitigation. The planning framework will integrate with a national system. Detailed implementation of inner urban redevelopment to promote mixed use at higher densities would be subject to planning provisions to suit local conditions.

The grounded theories are used to construct a developed integrated conceptual framework for the thesis in Chapter 7 Figure 7.2 (simplified form), which leads to recommendations for oil depletion planning policies and strategies applied to the reference City of Gold Coast and applicable in a wider western city context.

The integrated conceptual framework and the supporting research is offered as an original contribution of the thesis to sustainable planning theory and practice.

9.1.4 Synthesised findings for transformation of cities

The synthesised findings on the oil-constrained city of the future are presented in a consolidated summary that helps to contextualise the needed transformations. The uncertain transition from oil sufficiency to constraint is dependent upon demand and fracking of tight oil on a global scale. The IEA forecasts that conventional oil will only last another 50 or so years but tight oil and substitutes will allow moderate demand growth and a global population of nine billion by mid-century until renewable energy sources can replace oil and coal. Gas will become the new oil, but it too has a finite supply lasting in the order of 64 years until late-century under similar circumstances (IEA 2013: 72-73). It is therefore time to act now to plan oil depletion transformations.

29. This thesis finds that oil depletion manifests in the transport field, but indirectly affects all construction and building in multiple ways in the supply chain of refining materials to onsite assembly. Reducing petrol/diesel vehicle use is axiomatic.
30. More natural materials requiring less refining would be preferred. Urban metabolism favours locally sourced materials to produce modular building units in off-site manufacture using renewable electrically powered machinery that delivers low–medium rise buildings at urban densities.
31. Innovative technology relies on sensible changes to planning and building codes.
32. The aging population in detached housing will provide an ongoing turnover for families, as empty nesters move into regenerated development in localities with better amenities (the movers); or end their lives in place (the stayers) and share their housing with family or non-family housemates (the sharers).
33. Queensland's planning system is undergoing a profound change of direction and is expected to become more flexible in zoning of land uses, to embrace the form-based codes of the Next Generation Planning Handbook and the smart city growth movement. This land use pattern facilitates mixed use development more than traditional zoning. The grounded theories and the integrated conceptual framework provide a roadmap capable of guiding the strategic direction of the future planning system away from low density suburban sprawl.

34. The theories and conceptual framework applied in Chapter 7 to existing suburbs as a synthesised suburban transition model in Figure 7.4 suggest two contrasting scenarios in the transformation towards an oil-constrained future.

The suburban transition model and the supporting research are offered as an original contribution of the thesis to planning practice.

The model draws on the characteristics of sustainable cities in Chapter 6 to show hypothetical adaptive and maladaptive transition scenarios in three phases:

a. *the initial mitigation phase of oil depletion 2008-2018* (the oil peak plateau)

b. *the adaptation phase 2018-2025 w*hen oil depletion gradually becomes a significant transport constraint and society's dependency on oil becomes evident

c. *the oil-constrained phase after about 2025* with less energy and food security.

35. This research finds that local governments should aim for higher goals than current objectives set in legislated planning policies. These goals are summarised in five key principles, which will be appropriate from both an oil constraint and a climate change viewpoint and have general application in western cities:

a. The planning system delivers balanced outcomes and gives weight to the impacts of inevitable oil depletion and the benefits of renewable energy in considering the needs of current and future generations, based on best available knowledge.

b. Planning schemes limit the area of low density residential zone in new greenfield development in favour of urban consolidation in existing settlements within the statutory urban footprint. Inner-middle suburbs are redeveloped under a coordinated strategy, with mixed-use form-based urban structural unit (local area) plans to minimise suburban sprawl. The aim is to maximise use of established infrastructure and transport systems by reducing ad hoc redevelopment, at least cost to councils, developers, end buyers and the community.

c. Resilience planning of all existing suburbs under the state and local oil vulnerability strategies transforms most of the city towards an integrated public-active mobility oriented development (P-AMOD) focus. The walkable precincts extend to one kilometre/15 minute walking radius with increased density across each precinct. In P-AMOD precinct communities, the higher density supports more local employment and urban amenities in mixed use zones, supported by public and community based transport without the pressure for park-and-ride facilities.

d. Planning schemes incorporate the principles of urban metabolism and life cycle embodied/operational energy to inform evidence based planning of an efficient land use pattern to achieve sustainable regenerative environmental outcomes.

e. Infrastructure development programs are refocused in the short to medium term to prioritise oil and energy intensive projects for intra-urban and inter-urban development, public transport and renewable energy systems within each city and sub-regional area. This strategy minimises the cost rises anticipated to occur with oil depletion, which could jeopardise the feasibility of major infrastructure projects, and therefore increases resilience to future oil constraints.

36. The gradual onset of oil depletion after the peak oil plateau and the uncertainties surrounding global supply suggested in finding (34) categorise three general sequential pathways in strategic planning of urban residential form (without any timescale relevant to the City of Gold Coast and to other cities on a global scale:
    a. In the mitigation phase of conserving oil supply and reducing demand, long term planning strategies are devised and put in place as necessary.
    b. In the 'transitional city of tomorrow', resilient urban residential forms should anticipate the transformation needed to thrive in an oil-constrained future.
    c. In the 'oil-constrained city of the future', the transformation of urban forms will be ongoing as oil depletion impacts take effect in the urban environment.

9.2 Toward the cities of tomorrow and the oil-constrained future

The grounded theories developed in Chapter 7 suggested that Objective 3.3 could be demonstrated using a scenario approach.

Research objective 3.3 – Chapter 8

Demonstrate how land use planning can contribute to an orderly transformation of urban residential forms with reference to the selected Australian city.

Chapter 8 applies all the findings to the City of Gold Coast and presents those findings in three ways: how land use planning can contribute to an orderly transformation, and some of the barriers to overcome; the first phase of transition to a paradigm shift in planning for oil depletion; and the second phase of implementing the adaptive strategies in the transition to an oil-constrained future.

The Gold Coast transitional city of tomorrow

The immediate planning task is to consider the prudent precautionary short-to-medium term strategic responses to the peaking and depletion of global oil supply and the impacts on urban residential development (and indeed the whole city fabric). A well-known suite of more sustainable urban form models is available as readymade tools, ranging in scale from cohousing to new urbanism–smart growth, urban villages, regenerative ecocities concepts, and transition towns initiatives.

Land use planning innovation is demonstrated in the Gold Coast Labrador suburb to illustrate a scenario for urban renewal as an urban village close to the Southport central business district. This scenario is shown to represent a possible adaptive transformative oil depletion adaptation strategy, suggested in the model in Figure 7.4.

The Gold Coast oil-constrained city of the future

The grounded theories and models are applied to the Coomera-Pimpama area to demonstrate alternative scenarios of contrasting futures in the adaptive phase of oil constraints. In looking back nominally from 2042, the first scenario is maladaptive and the second has a more sustainable planning outcome for Coomera.

The maladapted scenario narrative portrays the effects of a business as usual low intensity urban form by the development industry in Coomera that ignores the oil adaptation and energy descent strategies until too late into the transitional phase. In the adaptive transformed future scenario, Coomera becomes a regenerative oil-constrained city, which looks beyond the oil-based economy.

The scenario planning method meets the aim of objective 3.3 to demonstrate that oil depletion is potentially a catalyst to create a sustainable future, guided by government led planning responses to the issues posed in the research problem. The findings of Part 3 are considered to be relevant to a wide spectrum of western cities.

9.3 Contributions to planning theory and practice

The significance of the thesis research is the contribution of knowledge towards extending planning theory and practice for sustainable development (SD). It aims to be a careful and comprehensive investigation of a complex global issue within the resource scope of a PhD, without excluding critical gaps in the existing knowledge and planning theory. The section also reflects on the thesis methodologies for their relevance to the research questions.

9.3.1 Contribution to sustainable development planning theory

The research is grounded in a sustainable development theoretical framework that has ranged over several disciplines in seeking answers to the research problem and questions. They include: urban planning theory, history and practice; urban morphology and urban design; architectural theory and history; ecological sustainable development theory and concepts; transport planning practice; urban metabolism and life cycle analysis; building theory and construction practice, quantity surveying and building economics; alternative fuels and renewable energy concepts; and climate change mitigation and adaptation strategies. Underlying and woven through these disciplines and concepts is the study of oil depletion, peak oil and all its implications for future urban form. The thesis contributes an integrated conceptual framework to define and operationalise sustainable urban form in an oil-constrained context that is applicable to several of the disciplines mentioned above. The findings have application in the Queensland and wider Australian context, and more generally in western cities, particularly those with a suburban pattern of urban form. The main contributions are:

1) The oil depletion and climate change mitigation and adaptation comparison leading to a set of terminology for oil depletion actions and adaptation strategies in section 9.1.1 is a contribution to extending SD planning theory.
2) The comprehensive definition of urban form in section 9.1.3 is offered as a contribution to urban morphology to describe the character of an urban area.
3) The set of four developed grounded theories in section 9.1.3 is offered as an original contribution to extending SD planning theory.

4) The integrated conceptual framework and the supporting research in section 9.1.3 are offered as an original contribution to extending SD planning theory and practice relating to urban metabolism concepts.

9.3.2 Contribution to sustainable development planning practice

The thesis contributes to sustainable planning practice by strongly suggesting that land use planning must contribute to an orderly transformation to an oil-constrained future to improve the resilience of urban residential forms through less oil-vulnerable development. The research is focused on developing the urban fabric; yet it acknowledges that transport is a critical underlying factor affecting all construction material handling and development activity, and so adversely affects urban planning.

As the planning system generally has a central aim to create sustainable urban forms, the thesis concludes that oil depletion strategies should influence land use planning policies by giving due weight to future oil constraints based on best available knowledge. The thesis suggests that oil adaptation strategies are likely to be more effective in framing government action and would contribute in a more positive way to climate change mitigation. Adaptive planning measures would be adjusted over time in ways that contribute to increasing resilience of human settlements to oil supply depletion. The alternative maladaptive strategies are considered to be untenable and are not in the public interest. The thesis concludes that while the grounded theories and models for sustainable urban residential development are demonstrated in the City of Gold Coast, the contributions have application in the management of existing Australian and western type cities. The main contributions to planning practice are:

1) The case studies and supporting data for a representative residential typology in the City of Gold Coast in section 9.1.2 are offered as an original contribution to SD planning practice.
2) The synthesised model of adaptive and maladaptive transition scenarios towards an oil-constrained future and the supporting research in section 9.1.4 are offered as an original contribution to SD planning practice.
3) The narrative scenarios of alternative Gold Coast development at the precinct scale are offered as an original contribution to SD planning practice.

9.3.3 Reflections on the thesis approach and research methodologies

The thesis has not attempted to produce an exhaustive catalogue of the contribution of oil and petroleum gas inputs to the modern city as part of the urban metabolism. The more modest aim is to examine the reliance on oil and gas as a fuel and on oil based products (Appendix B in the CDROM), and an oil-dependent facilitation of urban residential development processes; that might influence future urban form. Hence the metabolic outputs have been excluded from the research scope. Likewise the task of transitioning to renewable energy has been touched on as an important issue, but it has been well researched beyond the scope of this thesis (e.g. Droege 2006; Diesendorf

2007). The role of energy innovation and renewable energy are not discounted; they involve essential high and low technology solutions to the energy and mobility issues. The scope was also reduced by accepting and applying the large body of research about transport related aspects of material handling and freight movement, as well as public transport and general personal mobility.

The case studies in Chapter 5 are offered as essential components for a consistent comparison across the representative residential typologies of the reference City of Gold Coast. The detailed analysis of cases in Appendices C-G and other related material are included in the enclosed CDROM. The CDROM also contains supporting photographic and video data relating to the study of European and American cities, so only a representational sample is included in Chapter 6 to illustrate the concepts.

The research methodologies in Chapter 1 and Appendix A led to a three part, mixed methods approach summarised in Table 1.2 and Figure 1.5. The methodologies are considered to have been successfully applied to each part of the thesis, yielding 'a richer data set and triangulation of data collection and analysis to gain a more valid outcome than using only one method alone' (Morgan 2007: 71). The pilot case studies followed Yin (2009) with a protocol in Appendix A to ensure the results of each case are valid. The grounded theory approach was particularly useful in categorising the mass of data underlying Chapter 6 and has derived succinct theoretical concepts, from which to develop grounded theories and models in Chapter 7. The requirements of the Bond University ethics clearance RO1061 protected the interview anonymity in both the pilot case studies and the grounded theory verification. The anonymity deprived the opportunity to reveal the experience and expertise of the interviewees in Chapter 7, which would have added significantly to the weight of their evidence. However, the protection facilitated a frank interview discussion with experts employed in the state and local governments. The identities and interview transcripts are held by Bond University.

The structure of the thesis broadly follows the pattern suggested by Dunleavy (2003: 60) and is illustrated in Figure 1.6. It also follows his advice to write a research methods Appendix (2003: 61). This structure has allowed the core research to come earlier in the argument and results in a nine chapter thesis, plus appendices.

In summary, the thesis is considered to have employed appropriate methodologies to investigate a complex research problem and achieve interesting and valid theoretical and applied results. The contributions made by the research can be shared with the planning and related professions to address the emerging global wicked problem of oil depletion.

9.4 Recommendations for further research

No complex PhD thesis could claim to have fully covered the whole range of research possibilities contained within the problem statement (Dunleavy 2003: 40) and this thesis is no exception. Suggestions are made in the thesis for further research that is warranted on the topic. The following points briefly summarise the suggested topics:

a. Urban metabolic life cycle analysis is still under development in Australia. The thesis was to use the ALCAS database for the material flow analysis (MFA) of the case study data. However, it was not released by the completion of the case study research. The data gaps noted in section 5.7.3 and the embodied energy involved in land clearing and contouring operations could be filled by further research.
b. The outcomes of the pilot case study could be improved by additional cases to interpolate and extrapolate data to the full range of residential buildings. A second embedded unit of analysis in each case could also compare the use of alternative 'green' building materials and construction processes in more detail.
c. Strategies for economic incentives and innovative site amalgamation for urban densification programs that are outside the scope of the thesis warrant linking of this research to other disciplines.
d. The moderating planning and regulation factors that influence urban design of residential development warrant research in the Australian and wider context.
e. The planning system could facilitate regeneration and more affordable housing by considering a move away from freehold land tenure to leasehold, with renewal of a housing area at the end of the lease period (Neutze 1986). Leasehold can take into account economic, social and technological building obsolescence as an oil adaptation strategy (Newton 2010: 12). Although this concept is politically sensitive, further urban economic research is essential to pursue opportunities to reduce the cost of housing and facilitate reasonable urban densification.
f. In considering the spatial planning impacts of oil constraints on the built environment, the social question of community acceptance of radical changes to urban form proposed in Chapters 7 and 8 requires more social and demographic research through community engagement at the local and city-wide scales. Such research would include possible changes to land tenure suggested in (e) above.

These suggestions would be useful extensions to the thesis research, however the findings are not considered to be invalidated or unreasonably compromised by their omission.

Epilogue: Towards transformed oil-constrained cities

Following the yellow brick road to the emerald city **(Wizard of Oz)**

This chapter culminates the research journey in search of the sustainable city in the oil-constrained future—the oil-constrained city. A curious analogy is the Emerald City in the Wizard of Oz story. After a cataclysmic storm the heroine is transported to a mythical land and seeks to find answers and a way home in the fabulous city of the wizard. She is told to follow the yellow brick road that leads her group through various trials, obstacles and opposition by wicked witches to an uncertain destination. Reaching the goal of the Emerald City is analogous to the transformative process of taking small and large steps along the yellow brick road as the winding pathway to the oil-constrained city. Overcoming obstacles and opposition is akin to the process of addressing oil depletion as a wicked global problem—introduced in Chapter 1—and implementing adaptive strategies, even with uncertain consequences in a challenging environment. Not wishing to take this analogy to the extreme, the wizardry becomes the collective wisdom to guide us and the technological innovations to reduce oil dependency. Slaughter (2010: 170) describes this journey as heading towards 'wisdom cultures' that have 'access to advanced and sophisticated technologies which are guided by, held in balance by, higher-order values'. A similar imperative exists in addressing both oil depletion and climate change; if our civil society does not reach the goal to achieve the characteristics of an oil-constrained city, we may not get safely home (Register 2006: 309). But forget the sparkling red slippers: there is no magic solution. This analogy could be regarded as expressing the normative theory of a utopian scenario—e.g. the garden city, or Lynch's place utopia (1984: 293). Yet even the Emerald City had its shortcomings, as will the transformed oil-constrained cities. The challenge is to acknowledge oil depletion is an imminent wicked problem and start the journey. It will also need the Oz qualities of leadership, courage, wisdom and heart—or what Slaughter (2010: 188) terms 'cooperation, grace and purpose'—to get us there.

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